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Analysis of the Meteorology Associated With the 1998 NASA Glenn Twin Otter Icing Flights

Ben C. Bernstein
National Center for Atmospheric Research, Boulder, Colorado

November 2000

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Space Administration

Glenn Research Center

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Note that at the time of printing, the NASA Lewis Research Center
was undergoing a name change to the
NASA John H. Glenn Research Center at Lewis Field.
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Foreword

Supercooled Large Droplet (SLD) icing conditions were implicated in at least one recent aircraft crash, and have been associated with other aircraft incidents. Inflight encounters with SLD can result in ice accreting on unprotected areas of the wing where it can not be removed. Because this ice can adversely affect flight characteristics of some aircraft, there has been concern about flight safety in these conditions.

The FAA held a conference on in-flight icing in 1996 where the state of knowledge concerning SLD was explored. One outcome of these meetings was an identified need to acquire SLD flight research data, particularly in the Great Lakes Region. The flight research data was needed by the FAA to develop a better understanding of the meteorological characteristics associated with SLD and facilitate an assessment of existing aircraft icing certification regulations with respect to SLD.

In response to this need, NASA, the Federal Aviation Administration (FAA), and the National Center for Atmospheric Research (NCAR) conducted a cooperative icing flight research program to acquire SLD flight research data. The NASA Glenn Research Center's Twin Otter icing research aircraft was flown throughout the Great Lakes region during the winters of 1996-97 and 1997-98 to acquire SLD icing and meteorological data.

The NASA Twin Otter was instrumented to measure cloud microphysical properties (particle size, LWC, temperature, etc), capture images of wing and tail ice accretion, and then record the resultant effect on aircraft performance due to the ice accretion. A satellite telephone link enabled the researchers onboard the Twin Otter to communicate with NCAR meteorologists, who provided real-time guidance into SLD icing conditions. NCAR meteorologists also provided pre-flight SLD weather forecasts that were used to plan the research flights, and served as on-board researchers.

This report contains a description of the weather systems and meteorological features existing at the time SLD icing research flights were conducted during the winter of 1997-98. The information contained in this report complements microphysical data acquired during the SLD icing research flights, and provides a larger scale meteorological context for it. This combined set of microphysical and large scale weather features was intended to provide a basis for developing a better understanding of SLD and its formation mechanisms.

This report was prepared by Ben C. Bernstein of NCAR.

Table of Contents

Overview of Premier Cases

This part of the document contains a basic analysis of the meteorology associated with the NASA-Lewis Twin Otter icing encounters between December 1997 and March 1998. The purpose of this analysis is to provide a meteorological context for the aircraft data collected during these flights. For each case, the following data elements are presented:

1) A brief overview of the Twin Otter encounter, including locations, liquid water contents, temperatures and microphysical makeup of the clouds and precipitation aloft,
2) Upper-air charts, providing hand-analyzed locations of lows, troughs, ridges, saturated/unsaturated air, temperatures, warm/cold advection, and jet streams,
3) Balloon-borne soundings, providing vertical profiles of temperature, moisture and winds,
4) Infrared and visible satellite data, providing cloud locations and cloud top temperature,
5) 3-hourly surface charts, providing hand-analyzed locations of lows, highs, fronts, precipitation (including type) and cloud cover,
6) Hourly, regional radar mosaics, providing fine resolution of the locations of precipitation (including intensity and type), pilot reports of icing (including intensity and type), surface observations of precipitation type and Twin Otter tracks for a one hour window centered on the time of the radar data, and
7) Hourly plots of icing pilot reports, providing the icing intensity, icing type, icing altitudes and aircraft type.

Outages occurred in nearly every dataset at some point. All relevant data that was available is presented here. All times are in UTC and all heights are in feet above mean sea level (MSL).

Cases included

971209, 971211, 980112, 980122, 980126, 980127, 980129, 980130, 980204, 980205, 980212, 980219, 980224, 980227, 980302, 980305, 980318, 980320, and 980325.

Description of plots in this document

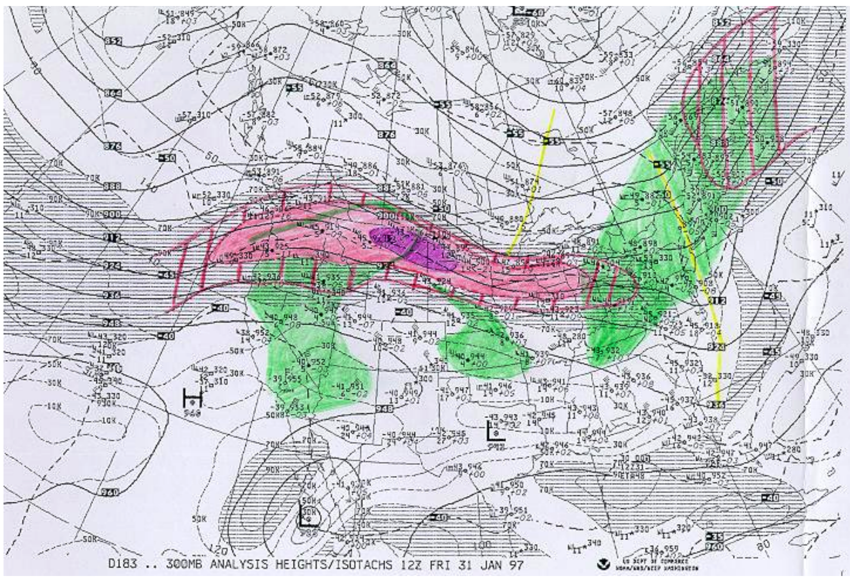
The following pages provide a complete description of the attributes of the plots that accompany each case, including the data elements covered and how they have been represented.

Upper-air charts

Analyses are made at 300, 500, 700 and 850 mb. On all charts, trough axes are indicated as yellow lines, and areas of saturated/near-saturated conditions are shaded green. Saturated/near-saturated conditions are those where the dew-point depression (temperature minus the dew point; DDP) is < 8 C at 300 mb and < 5 C at 500, 700 and 850 mb. Contours of constant geopotential height (MSL) are indicated as solid black lines, while contours of constant temperature are indicated as dashed black lines.

On 300 mb charts, jet stream winds are indicated as follows: > 150 knots in purple, > 110 knots in red, > 90 knots in red-hatching.

On 500, 700 and 850 mb charts, dry areas (DDP > 10 C) are shaded orange, isotherms (lines of constant temperature) are brown, areas of warm and cold temperature advection (the wind is bringing in warmer or colder air, respectively) are indicated with red and blue arrows, respectively. The arrows indicate the direction of the warm or cold advection.



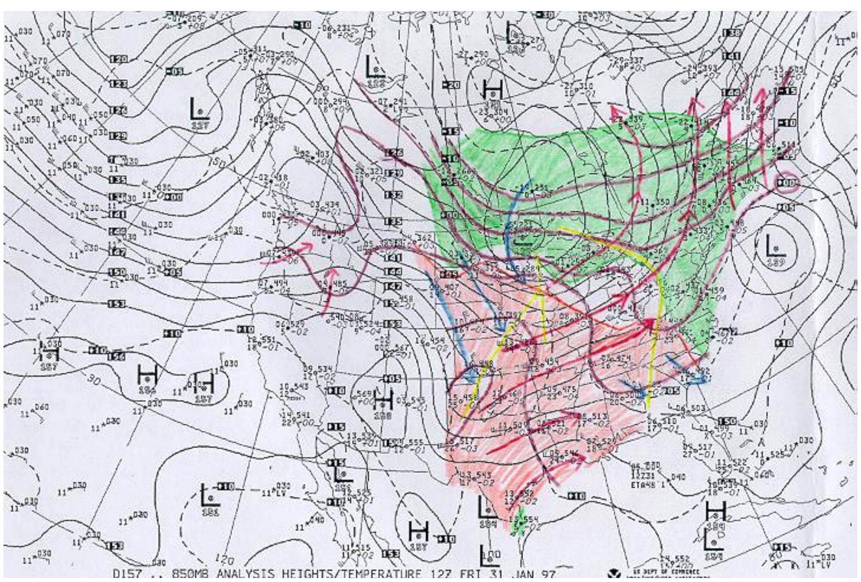


Figure 1 – Example upper-air charts at 300 and 850 mb.

Balloon-borne soundings

On sounding charts, profiles of temperature, dew point and winds are plotted. Solid lines of constant temperature are skewed, run from the lower left to the upper right, and are given every 10 C. Altitude is indicated on the left side of the chart in kilometers. Wind barbs are given on the right hand side of the chart, where a half-barb indicates 5 knots, a full barb indicates 10 knots and a flag indicates 50 knots of wind speed. The wind barbs indicate the direction that the wind is from.

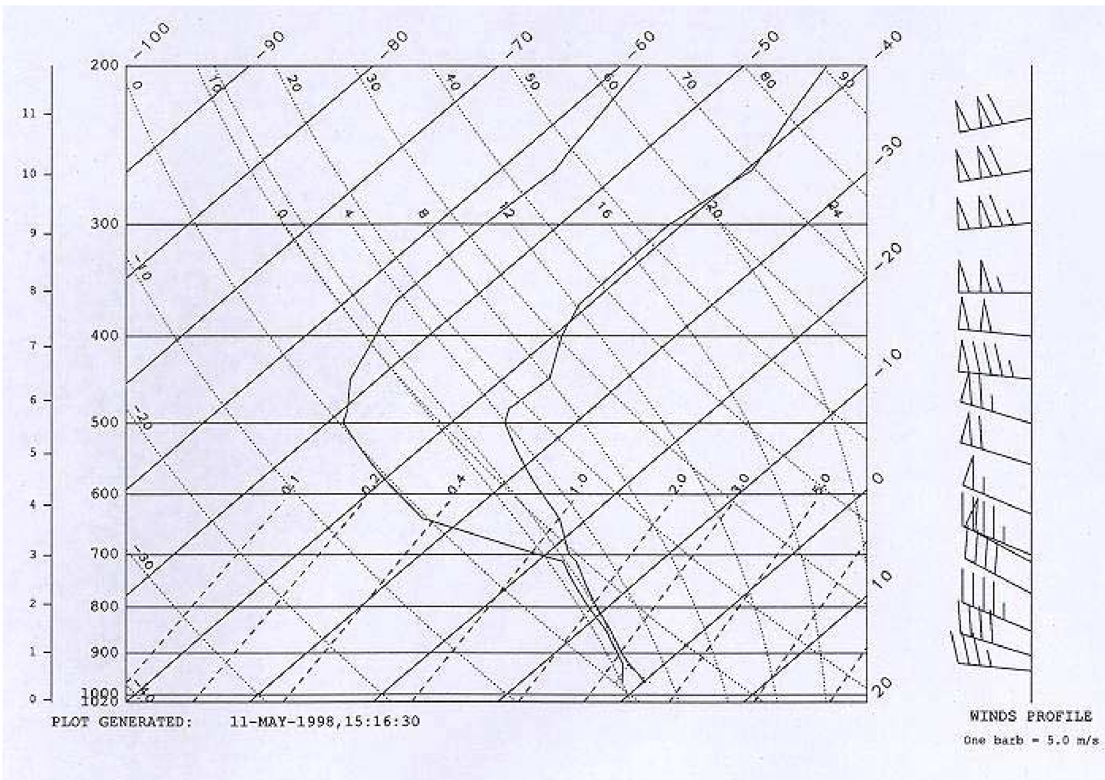
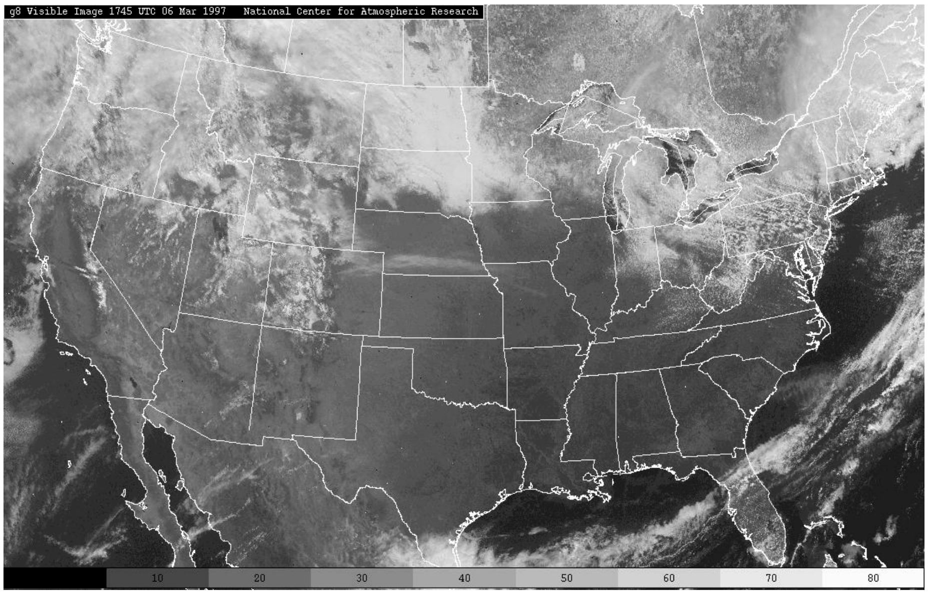


Figure 2 – Example of balloon-borne sounding data.

Satellite imagery

On visible satellite images, clouds and snow cover show up as white/bright areas, while ground and water typically show up as black/dark areas. On infrared satellite images, the temperature of the cloud top, ground, or water are indicated. Temperature ranges for each color on infrared imagery are given at the bottom of each image. Each color represents a 5 C range of temperature values (e.g. –12.5 to –7.5 C), and the number (e.g. –10) represents the central temperature value for that color.



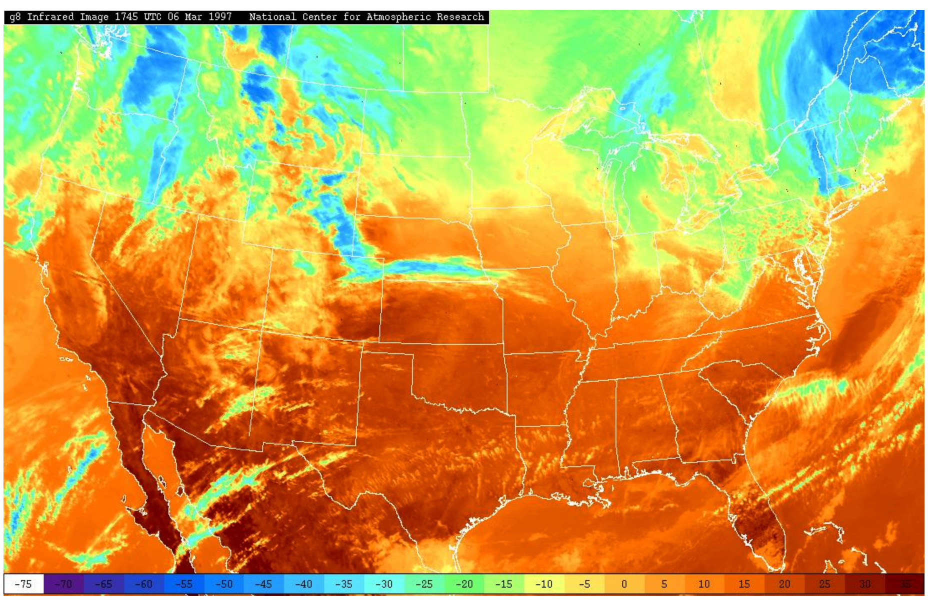


Figure 3 – Example visible and infrared satellite images.

Surface charts

On surface charts, high pressure centers are indicated with an ‘H’, low pressure centers are indicated with an ‘L’, and contours of constant pressure are indicated with solid black lines. Fronts are indicated as heavy black lines with: cold fronts - pointed barbs, warm fronts - rounded barbs, stationary fronts - pointed barbs on one side and rounded barbs on the other, and occluded fronts - pointed and rounded barbs on the same side. Trough axes are indicated with dashed lines. Precipitation areas are shaded as follows: rain/drizzle – green, snow – blue, freezing precipitation (ZL, ZR, IP) – red.

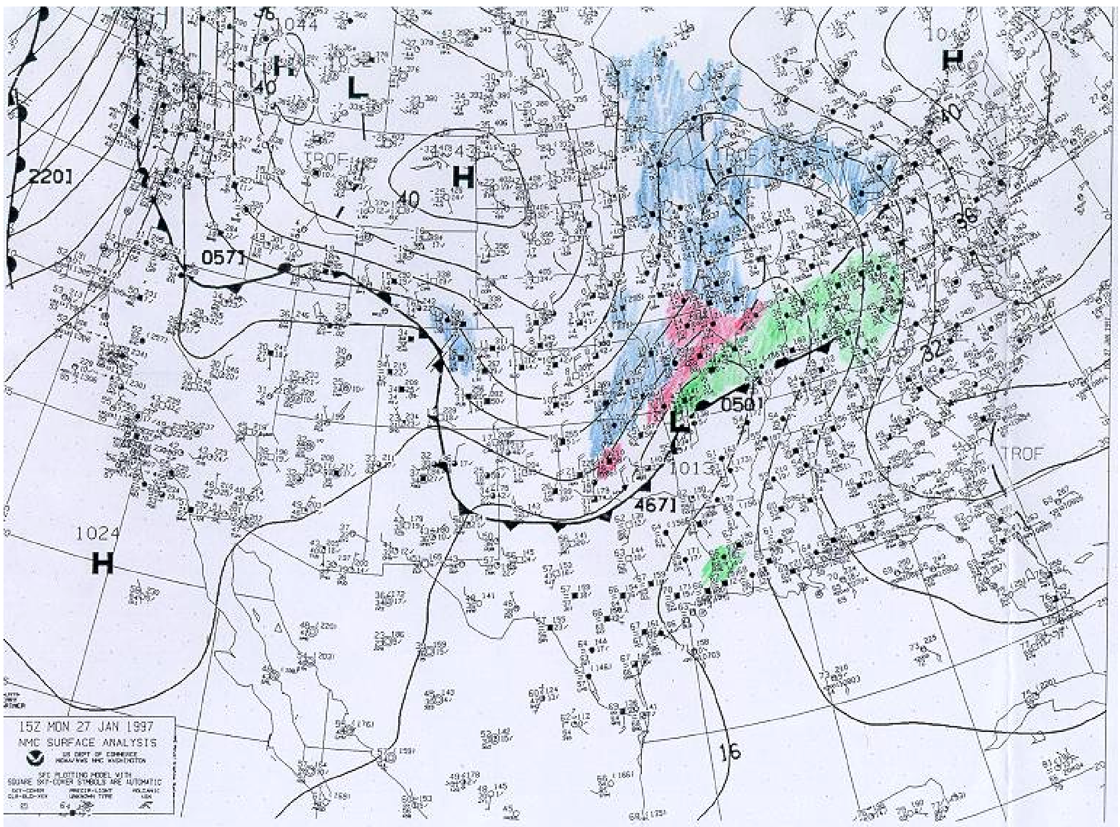


Figure 4 – Example surface chart.

Radar mosaic charts

On regional radar mosaic charts, locations of precipitation with radar reflectivity values of at least VIP 1 (>18 dBZ) are given. The precipitation is color-coded by precipitation type (freezing precipitation (ZL, ZR, IP) - red and magenta, rain - green and yellow, snow - blue) and intensity (VIP level 1-6). A color bar indicating precipitation type and intensity can be found at the bottom of each chart. Pilot reports of icing are indicated as follows:

ICING TYPES –

R=rime, C=clear/glaze, X=mixed, U=unknown

ICING INTENSITIES –

small font = trace, trace-light or light

medium font = light-moderate or moderate

large font = moderate-severe or severe

NASA Twin Otter tracks are plotted for a one-hour time window centered on the valid time of the chart. A '+' is plotted at the aircraft's location every 2 minutes, and an 'x' is plotted at the aircraft's location every 10 minutes.

Precipitation type reported by surface stations is also plotted in yellow. The symbols for the precipitation type are given at the bottom-right portion of the chart.

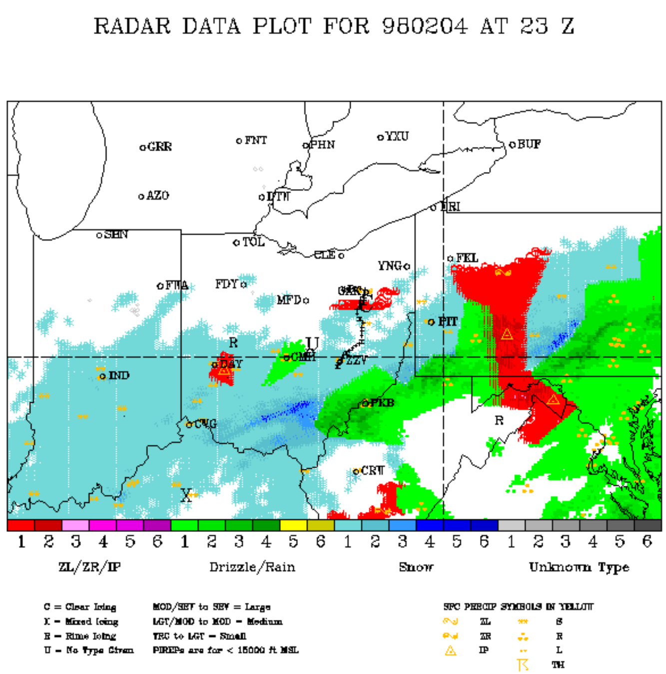


Figure 5 – Example regional radar mosaic chart.

Pilot reports of icing

Pilot reports (PIREPs) of icing are given for a one hour time window which is indicated at the top of the chart. Icing PIREP indicators are given at the bottom of the chart. The size and color of the PIREP indicates its intensity, while the letter plotted indicates its type (R=rime, C=clear/glaze, X=mixed, U=unknown). The aircraft type is plotted just up and to the right of the R, C, X or U, and the base and top of the reported icing altitudes are given just below the aircraft type (100's of feet MSL).

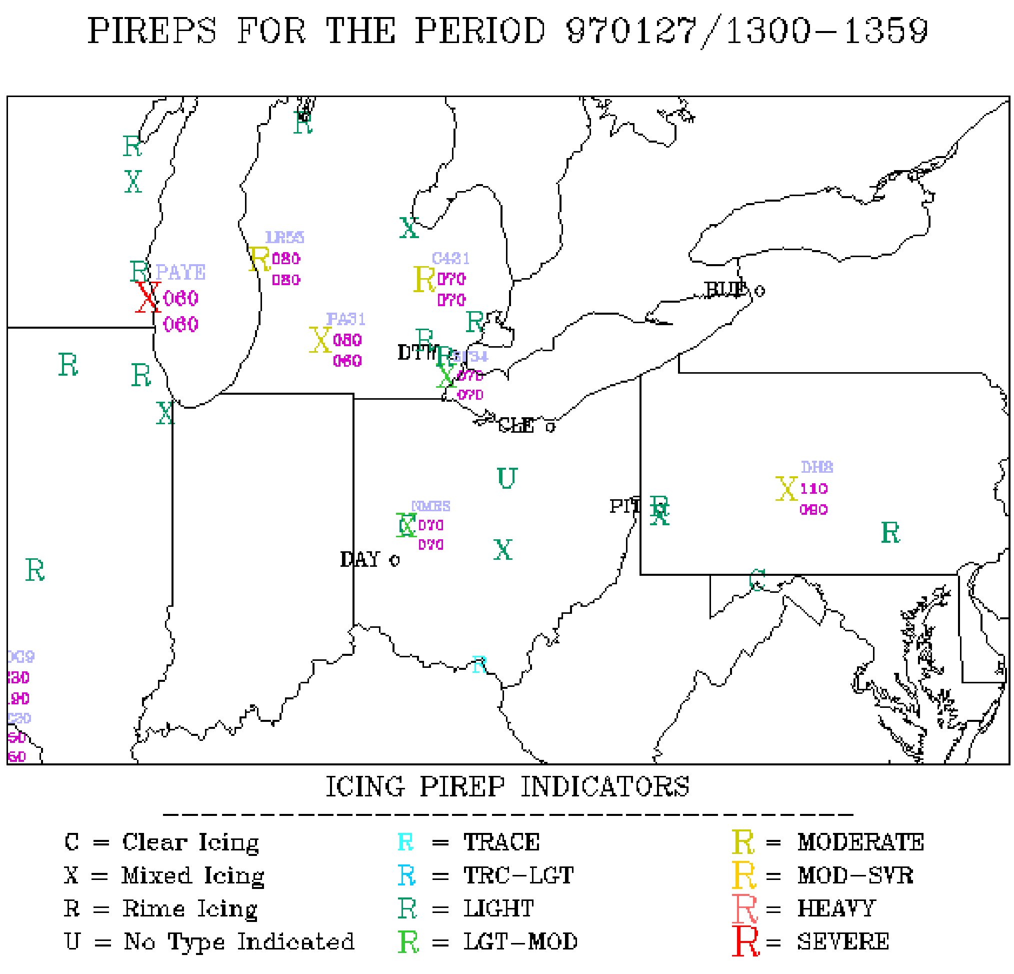
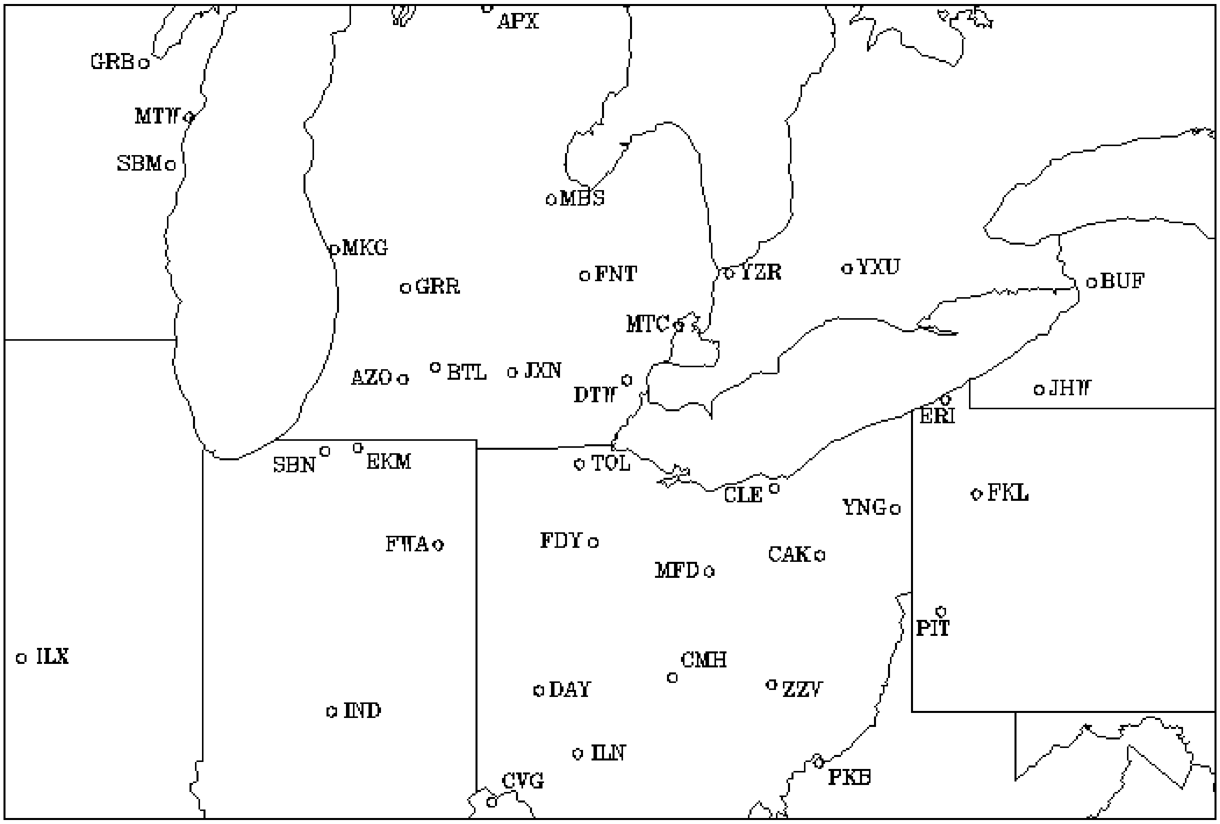


Figure 6 – Example plot of icing pilot reports.

Station locations

A map of commonly referenced station locations, as well as the matching 3-letter codes is given below. This map covers what is referred to in the document as the "forecast area."



CODE	STATION NAME
CLE	Cleveland, Ohio
CAK	Canton-Akron, Ohio
CMH	Columbus, Ohio
DAY	Dayton, Ohio
FDY	Findlay, Ohio
ILN*	Wilmington, Ohio
MFD	Mansfield, Ohio
TOL	Toledo, Ohio
YNG	Youngstown, Ohio
ZZV	Zanesville, Ohio
CVG	Covington, Kentucky (Cincinnati)
ILX*	Lincoln, Illinois
EKM	Elkhart, Indiana
FWA	Fort Wayne, Indiana
IND	Indianapolis, Indiana
SBN	South Bend, Indiana
APX*	Alpena, Michigan
BTL	Battle Creek, Michigan
DTW*	Detroit, Michigan
FNT	Flint, Michigan

CODE	STATION NAME
GRR	Grand Rapids, Michigan
JXN	Jackson, Michigan
MBS	Saginaw, Michigan
MKG	Muskegon, Michigan
MTC	Selfridge AFB, Michigan
BUF*	Buffalo, New York
JHW	Jamestown, New York
YXU	London, Ontario
YZR	Sarnia, Ontario
ERI	Erie, Pennsylvania
FKL	Franklin, Pennsylvania
PIT*	Pittsburgh, Pennsylvania
PKB	Parkersburg, West Virginia
GRB*	Green Bay, Wisconsin
MTW	Manitowoc, Wisconsin
SBM	Sheboygan, Wisconsin

* denotes a sounding site

December 9, 1997

Flight #1—Over Mansfield and Findlay, OH, from 1453 to 1635 UTC.

Flight #2—Over Mansfield and Cleveland, OH, from 1808 to 1829 UTC.

Brief overview

Two flights were made on this day. During the first flight, the Twin Otter primarily sampled two cloud decks over the Mansfield (MFD) and Findlay (FDY) areas, from 3500 to 7200 feet and 10200 to 11400 feet. The upper cloud deck contained small droplets and some ice crystals, with peak LWCs of 0.25, and temperatures between –8 and –10C (cloud top temperature). Snow crystals were observed beneath the upper cloud deck, and reached the lower cloud deck near Cleveland and FDY, but did not do so over MFD. The lower cloud deck contained mostly liquid water, but also had some snow crystals (especially north of MFD), peak LWCs of 0.3, and a cloud top temperature of –2C. Freezing drizzle was found within and below the lower cloud deck from ~6000 feet down to ~1300 feet, depending upon the location. Static temperatures were fairly warm (T > -3C), and liquid water contents fairly low (LWC < 0.15) when ZL was present. Some snow crystals were present during periods of ZL and small-drop-only conditions.

The second flight was essentially a ferry flight from Mansfield back to Cleveland. Similar conditions to those found during the first flight were sampled as the Twin Otter cruised at 3000 feet. Freezing drizzle was sampled north of Mansfield, but became rather spotty near Cleveland.

Relevant weather features

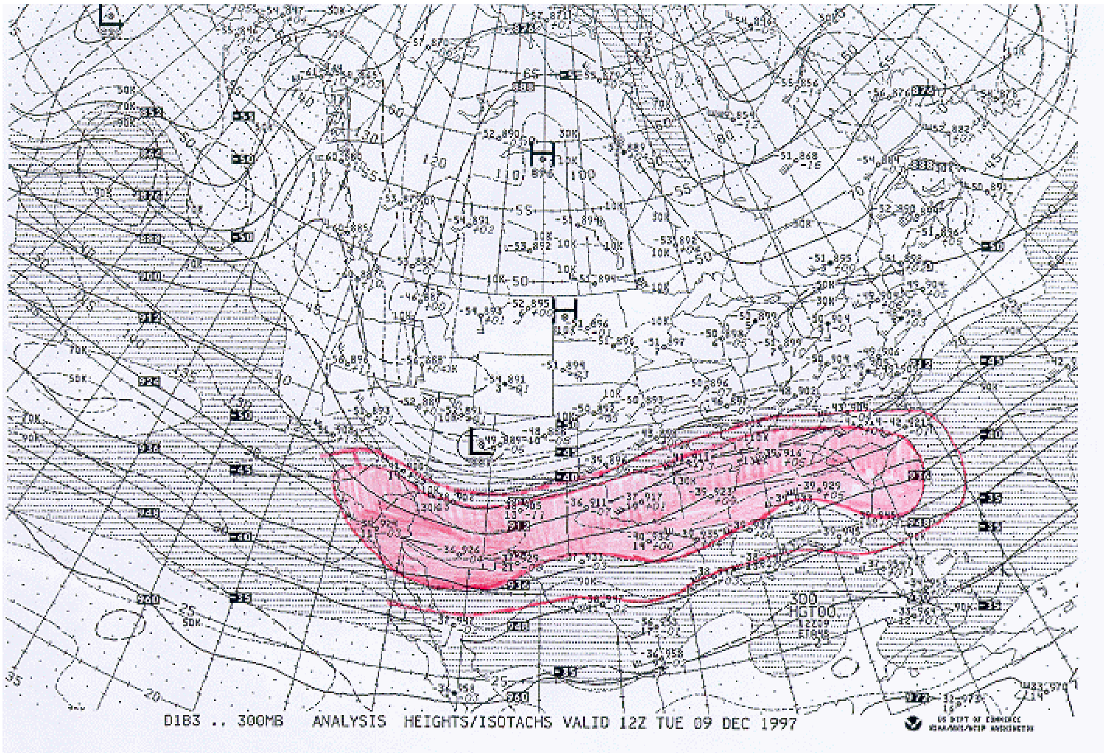
The 300 mb chart (Fig. 1) shows that the jet was well to the south of the forecast area, while a trough ran from west to east across the southern end of the Great Lakes. The trough was weaker, but still evident at 500 mb, and extended westward to meet up with another trough that arced across Iowa and Nebraska into a closed low over southwestern Kansas. Some warm advection was found to the north of the Ohio-Indiana area trough axis. A swath of moisture was found across the northeastern half of Ohio, where temperatures were -20 to –25C. Additional moisture was in place to the north, northwest, and west of Ohio, but very dry air was moving in from the southwest. This is especially evident at Wilmington Ohio, whose sounding featured dry air down to ~660 mb (~12,000 feet – Fig. 2). The Detroit sounding had deep moisture above 670 mb, and dry air below to the top of a lower cloud deck at 860 mb, with subfreezing cloud below that level. The 700 mb chart matches this situation well, showing a swath of moisture over the southeastern two-thirds of Ohio (-10C < T < -5C), and very dry air to the north. The trough axis was slightly further south at this level, and extended westward to a weak low over Nebraska. Warm advection was prevalent from Lake Erie southward into Kentucky. A swath of moisture extended from northwest to southeast across Ohio, while dry air was in place over and south of southwestern Kentucky. At 850 mb, the trough was to south of Cleveland, near Mansfield, and warm advection was in place across the entire forecast area. The moisture swath was much broader, and covered most of the Midwest and Appalachians,

roughly to the south of a line from Atlantic City to Green Bay. Temperatures were just below freezing in the moisture at this level. The 1200 UTC Wilmington sounding showed strong stability up to ~820 mb, and more weakly stable lapse rates to 750 mb, with a more unstable profile to the apparent cloud top at 660 mb. The Detroit sounding was slightly unstable from the surface to 880 mb (top of the lower cloud deck), then strongly stable in the dry layer above.

The infrared satellite image for 1215 UTC (Fig. 3) reflects the upper air patterns well, with widespread cloud across the forecast area and colder cloud tops (CTT < -15C) over Michigan and the northeastern half of Ohio, with warmer cloud tops (CTTs near -10C) over southwestern Ohio, southern Indiana, and Kentucky. Visible and infrared imagery for 1415 UTC shows the widespread cloudiness and that the colder clouds moved toward the northeast with time, leaving CTTs > -15C over most of Ohio. Little changed after 1415 UTC, though the few remaining cold clouds over the northeastern corner of Ohio moved off. Left behind was widespread cloud with CTTs rising from -14C to -10C from north to south.

The 1500 UTC surface map (Fig. 4 - 1200 UTC not available) had a 1000 mb occluded low over the Oklahoma panhandle. The occluded front extended across Oklahoma, then broke into a cold front that ran south into Texas and a warm front that ran southeast into Georgia. A surface trough was evident across central Illinois, Indiana, Ohio, and West Virginia, and winds shifted from southeasterly to easterly across it. An amorphous 1020 mb high was in place across southern Ontario and New England, which kept cold air in place and supplied a situation for weak overrunning. Widespread light snow was found in areas of colder cloud tops to the north of the trough axis, except where it became discontinuous over northern Ohio. Some freezing drizzle was reported at several stations in southwestern Ohio between 1300 and 1600 UTC. Only patchy drizzle observations occurred after that, mostly near Dayton and Columbus, while patches of light snow dissipated and moved northward across northern Ohio, leaving the only overcast conditions in their wake. The trough axis across Ohio moved slightly northward to Mansfield by 1800 UTC.

The regional radar mosaic for 1300 UTC (Fig. 5) shows the solid swath of snow across Lake Michigan and southwestern Michigan, with patchy snow over the northeastern half of Ohio, patchy freezing drizzle in the Columbus/Dayton area, and drizzle near Cincinnati. The echoes over Ohio slowly dissipated after 1500 UTC, but were still present near Mansfield and Findlay during the first flight. Only a little echo was evident in the immediate vicinity of the flight. The echoes dissipated further by the start of the second flight, which took place almost entirely in areas with overcast conditions to the south of some light snow reported near Cleveland. The patchy echo and few surface observations of light snow match the observations of off and on mixed and all-water conditions aloft. Surface observations of freezing drizzle and drizzle were mostly found just to the south of the area where the aircraft flew and observed freezing drizzle aloft. This was the case because enough dry air was in place at low levels over Mansfield to keep the freezing drizzle from reaching the surface there. Lots of moderate and light mixed and rime PIREPs were found across the area, mostly between 7,000 and 11,000 feet (Fig. 6). Some moderate PIREPs were found at lower altitudes near Detroit.



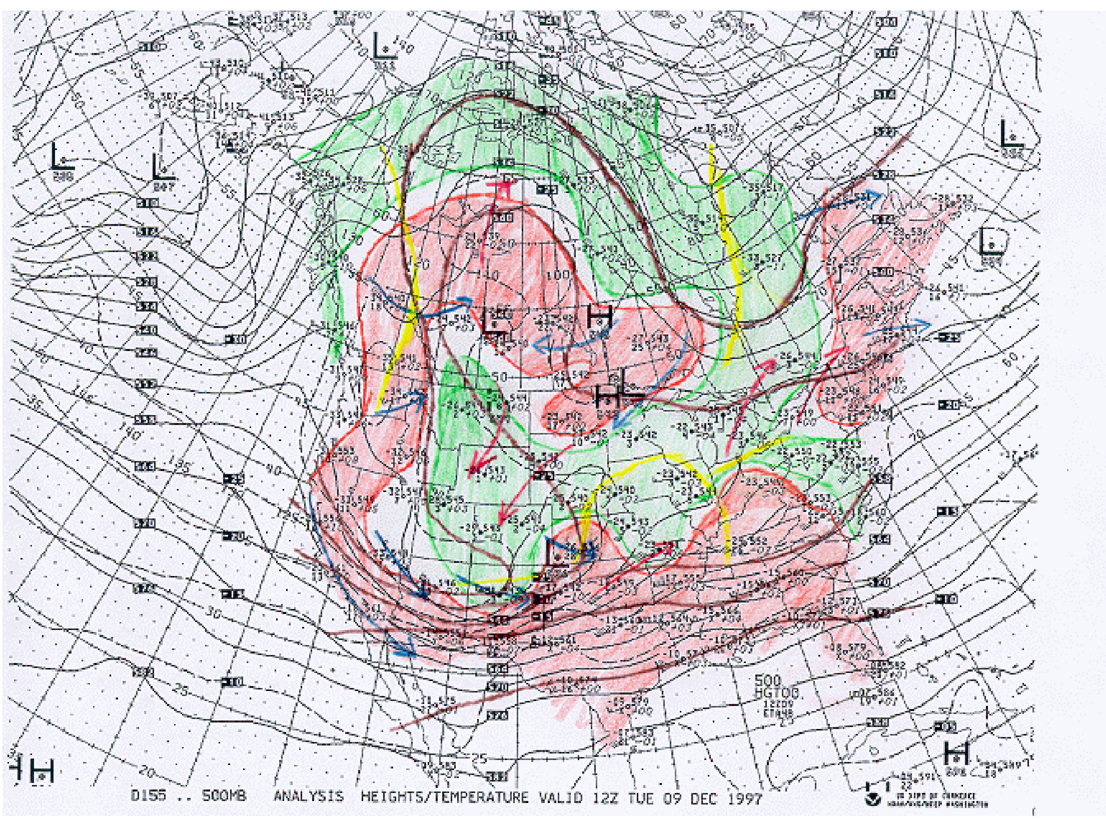
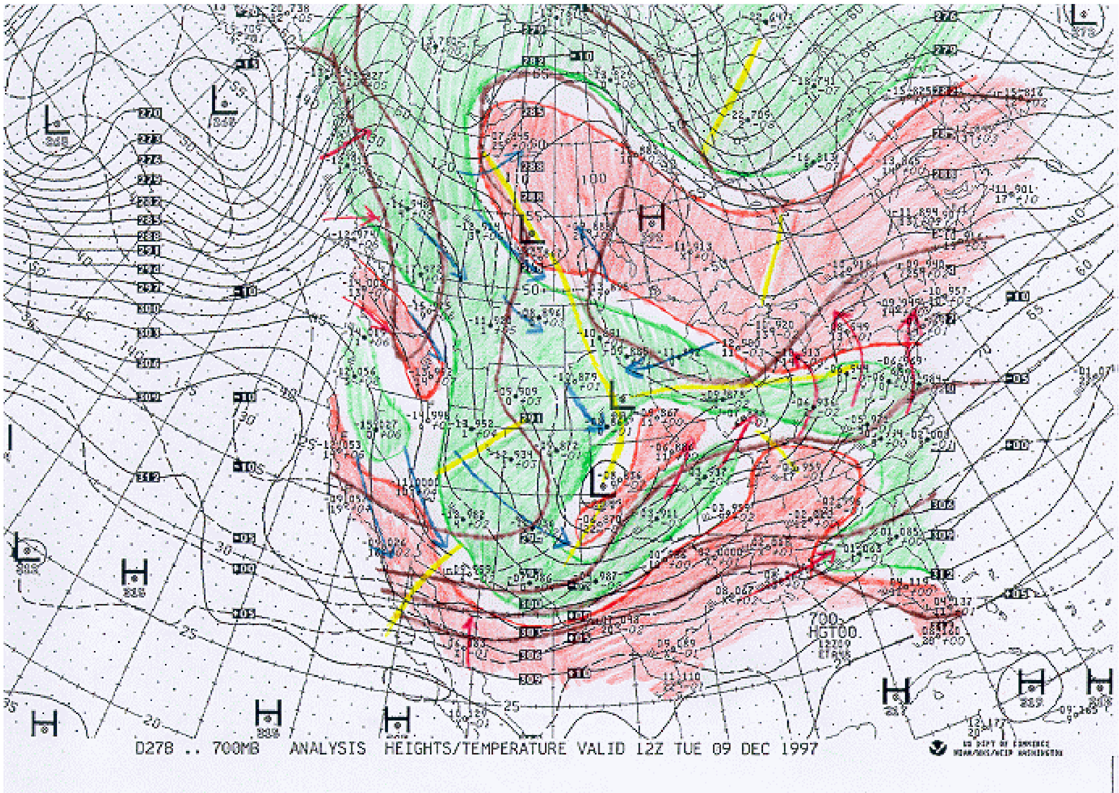


Figure 1 – Upper-air charts for 971209, 1200 UTC at a) 300 and b) 500 mb.



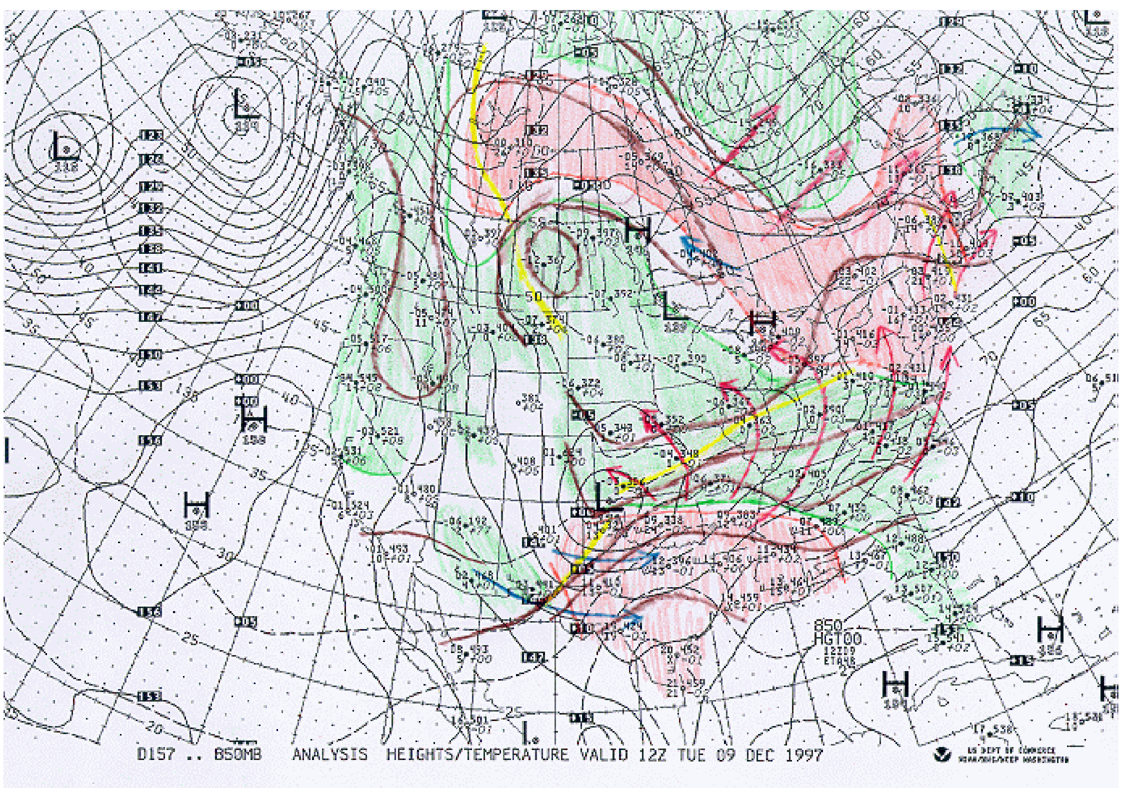


Figure 1 – Upper-air charts for 971209, 1200 UTC at c) 700 and d) 850 mb.

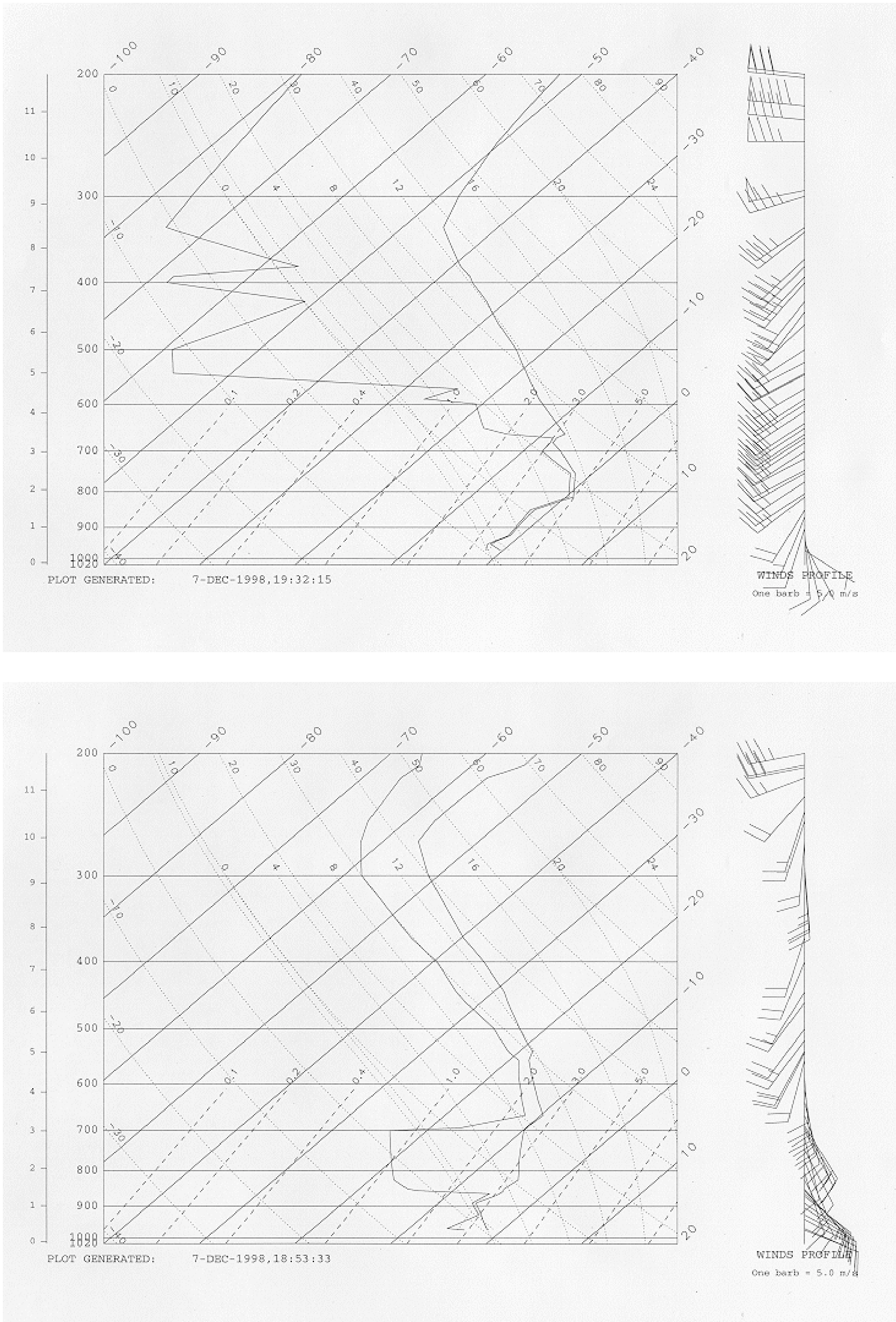


Figure 2 – Balloon-borne soundings from a) Wilmington and b) Detroit for 971209, 1200 UTC.

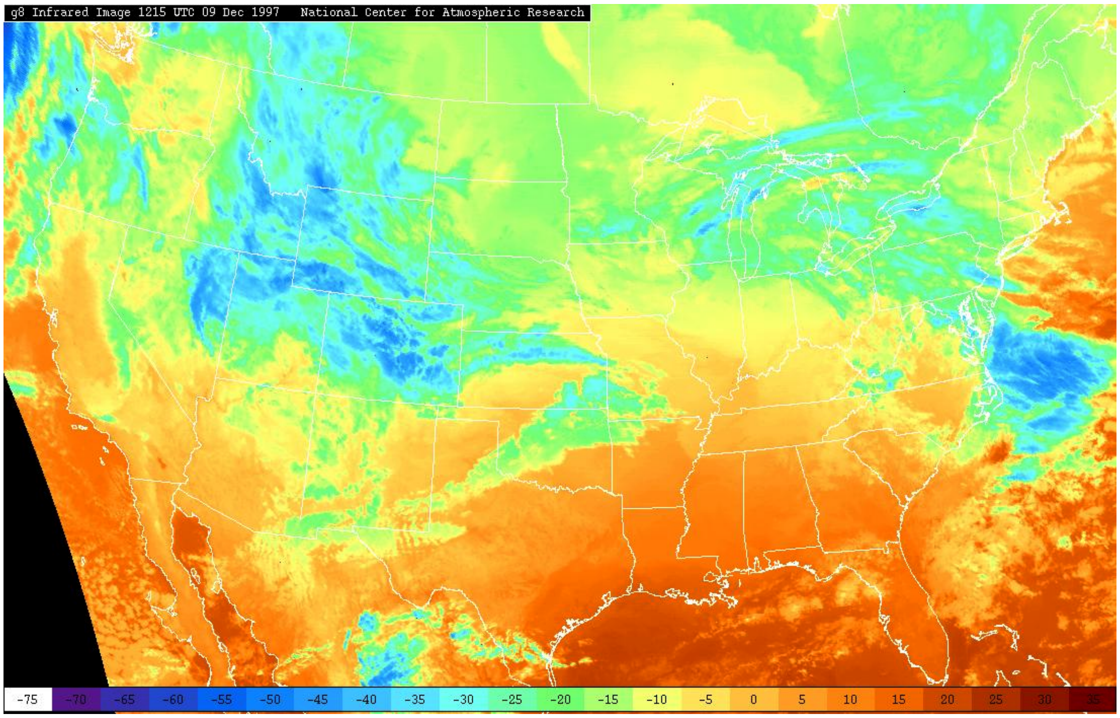
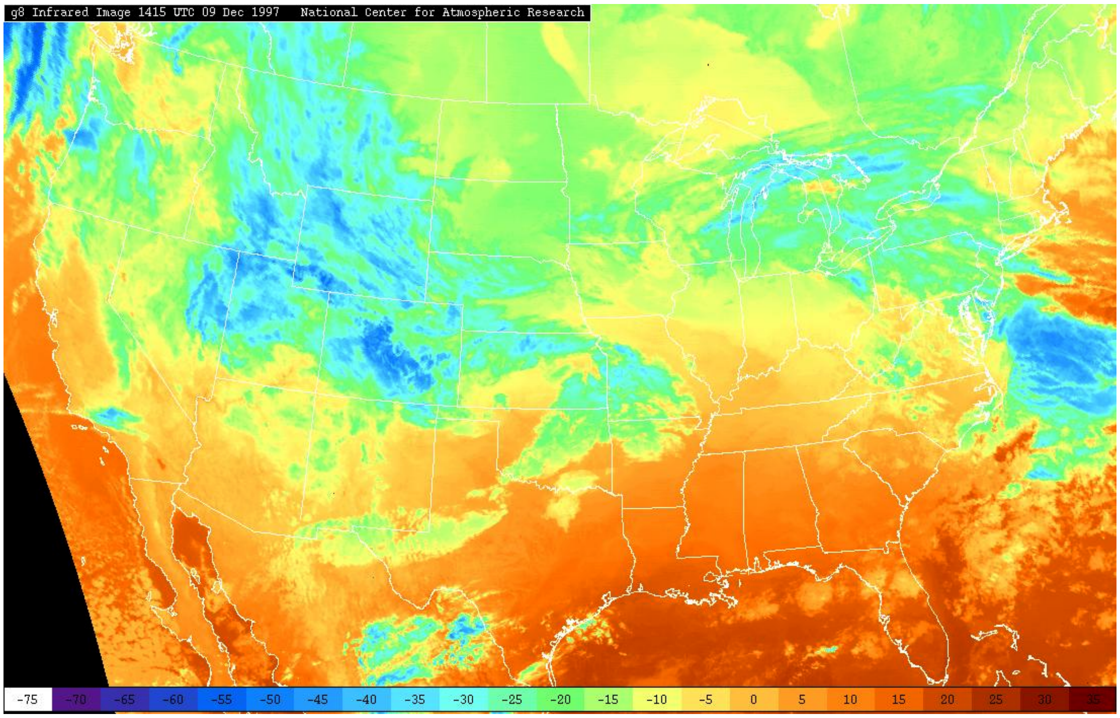


Figure 3 – GOES-8 a) infrared satellite image for 971209, 1215 UTC.



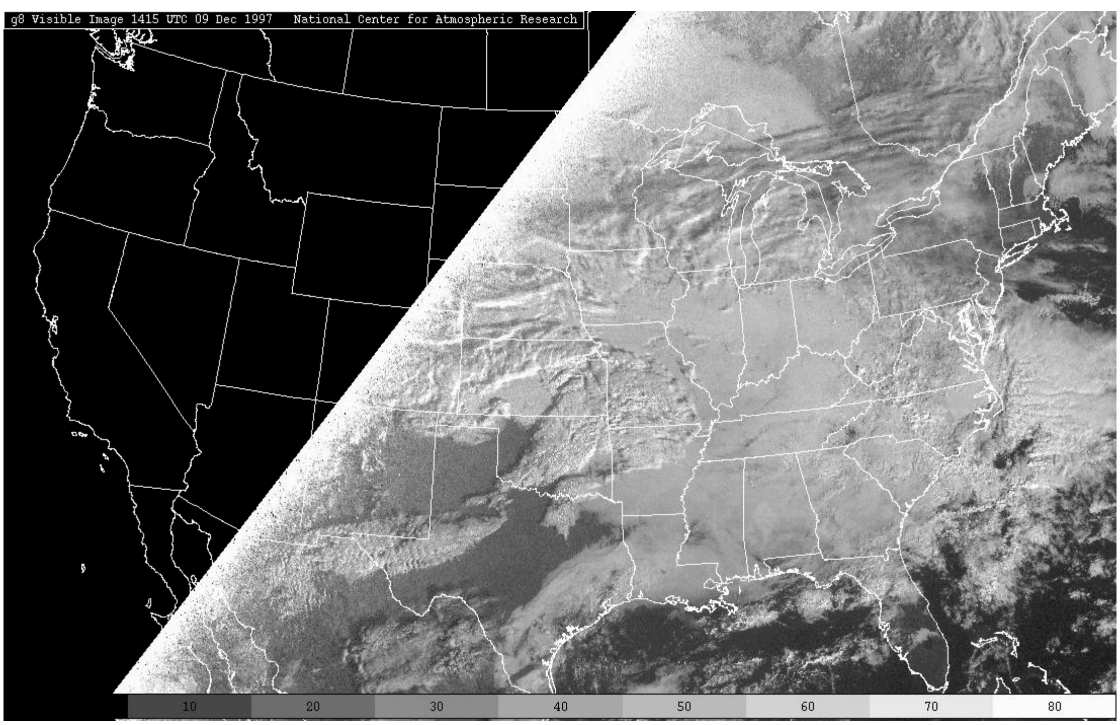
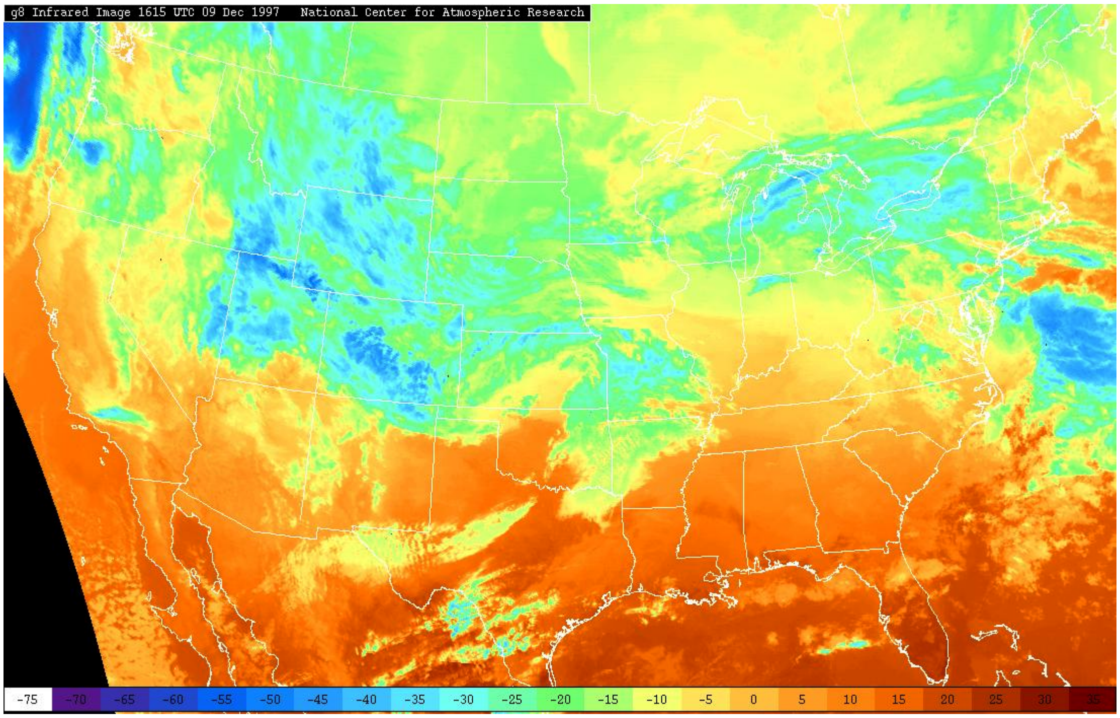


Figure 3 – GOES-8 b) infrared and c) visible satellite images for 971209, 1415 UTC.



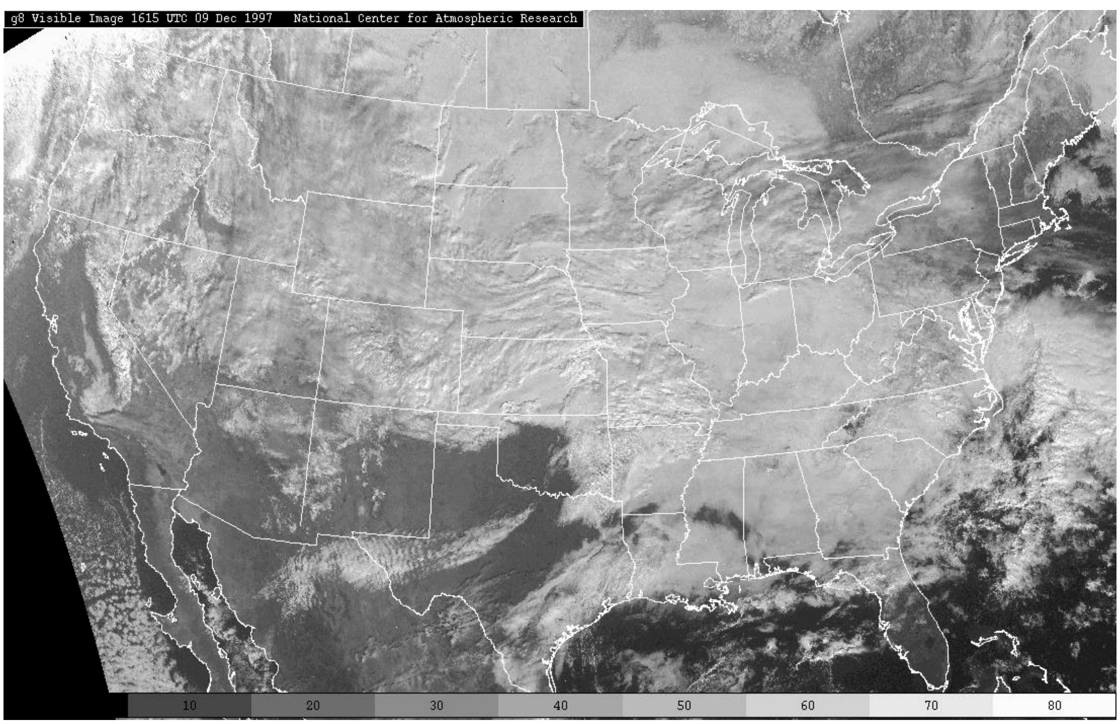
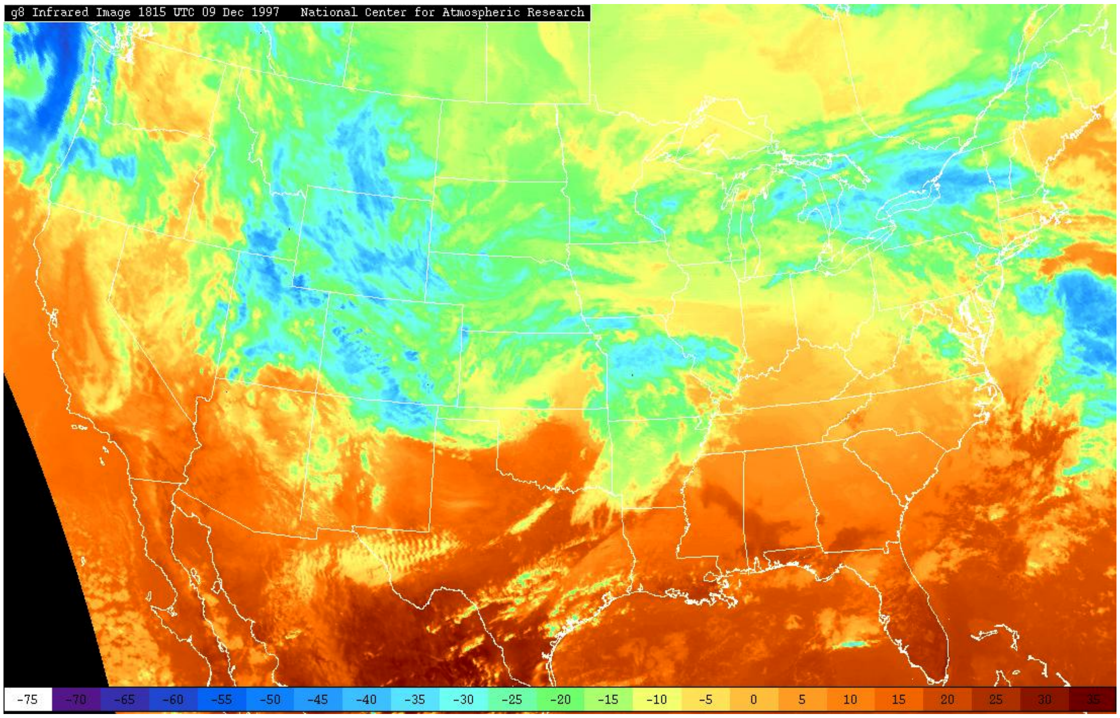


Figure 3 – GOES-8 d) infrared and e) visible satellite images for 971209, 1615 UTC.



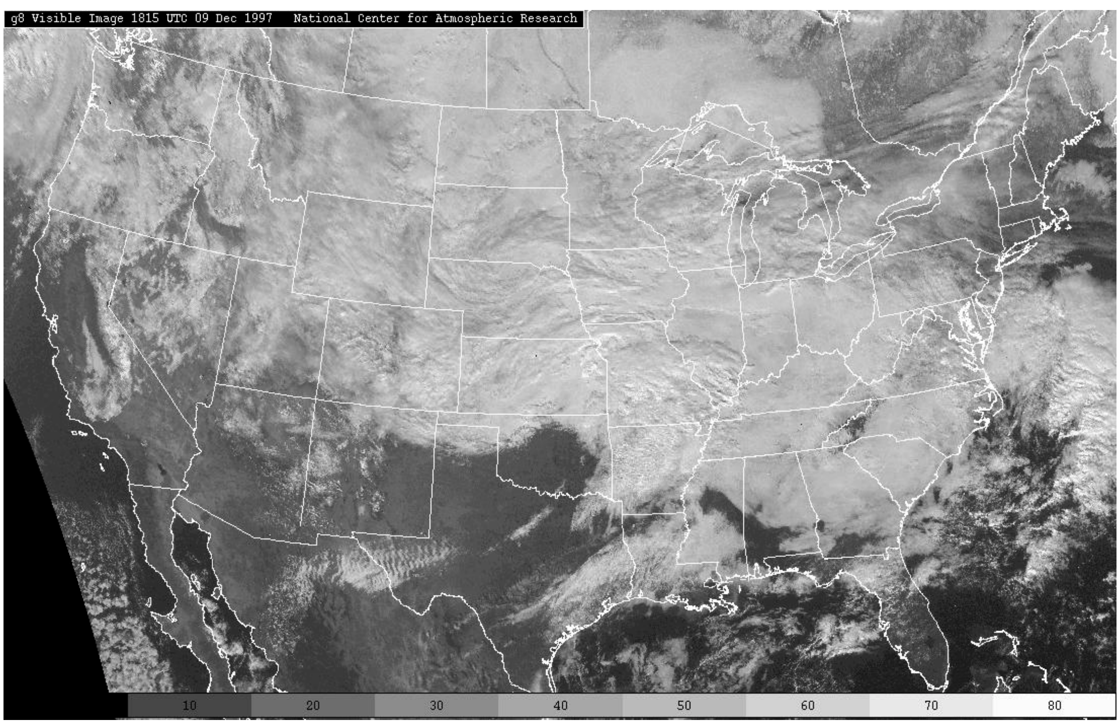


Figure 3 – GOES-8 f) infrared and g) visible satellite images for 971209, 1815 UTC.

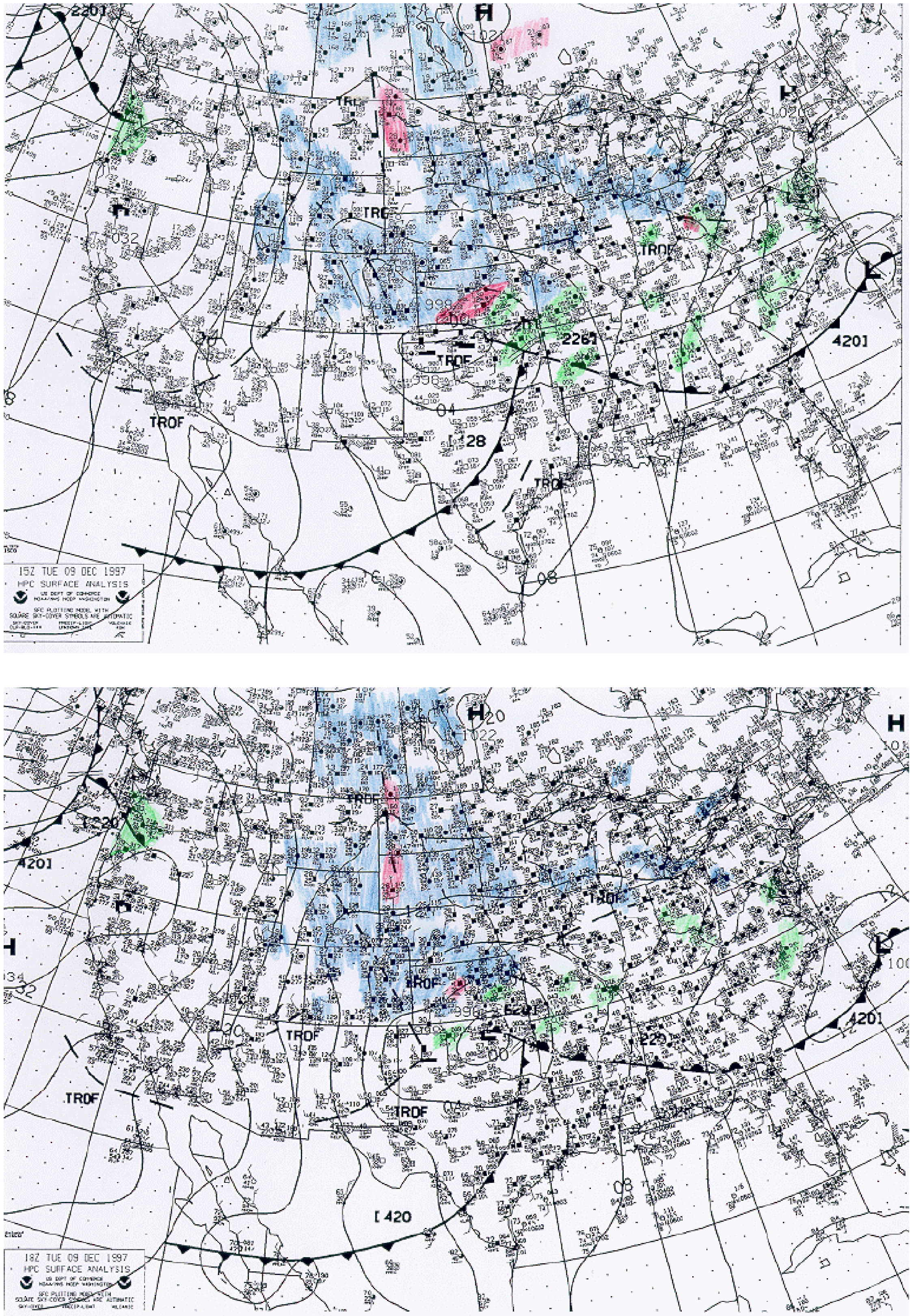
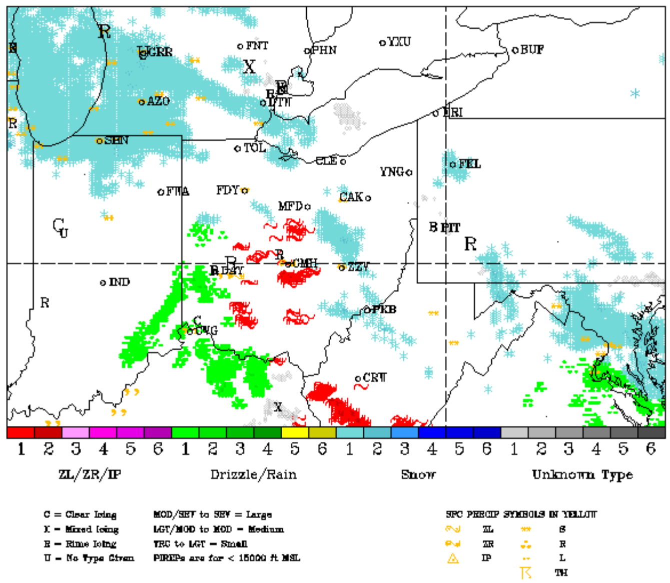


Figure 4 – Surface charts for 971209, a) 1500 and b) 1800 UTC.

RADAR DATA PLOT FOR 971209 AT 13 Z



RADAR DATA PLOT FOR 971209 AT 14 Z

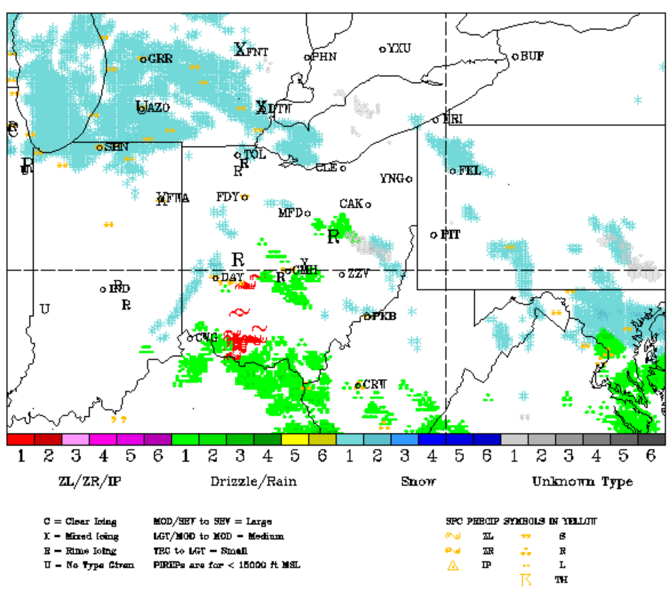
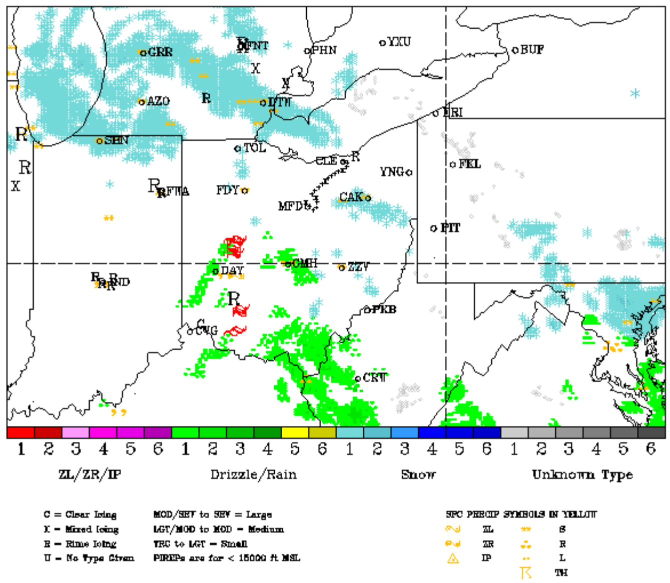


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 971209, a) 1300 and b) 1400 UTC.

RADAR DATA PLOT FOR 971209 AT 15 Z



RADAR DATA PLOT FOR 971209 AT 16 Z

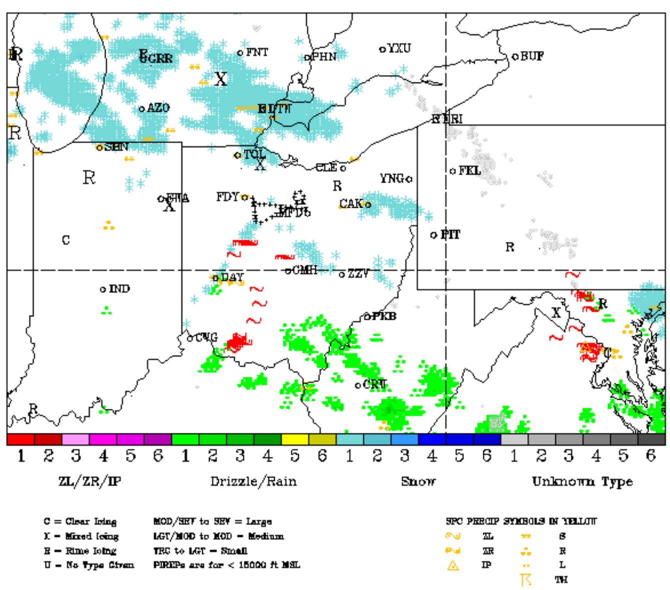
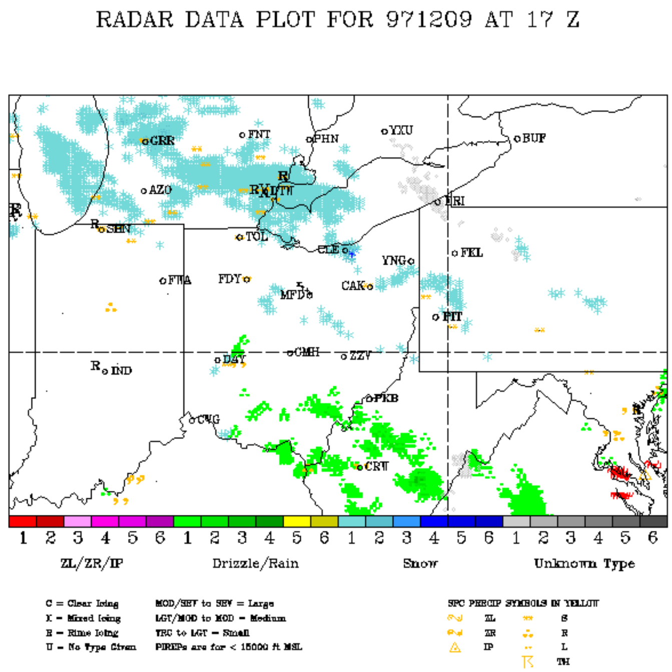


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 971209, c) 1500 and d) 1600 UTC.



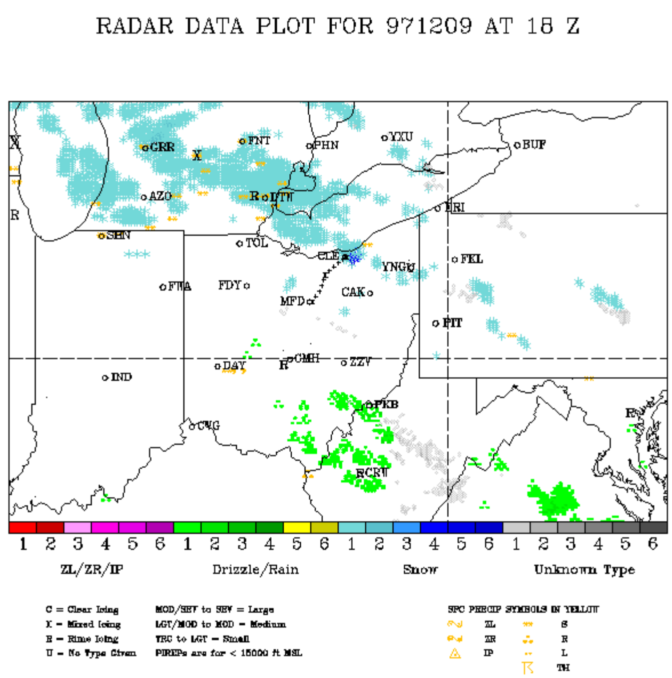
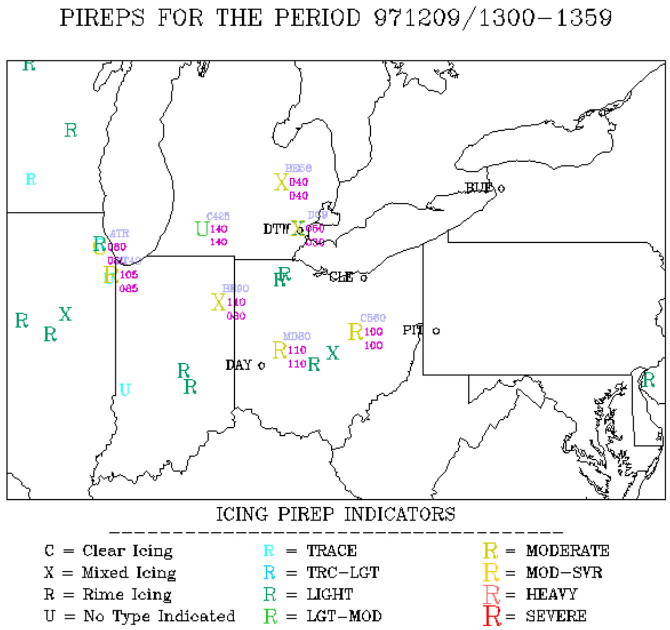


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 971209, e) 1700 and f) 1800 UTC.



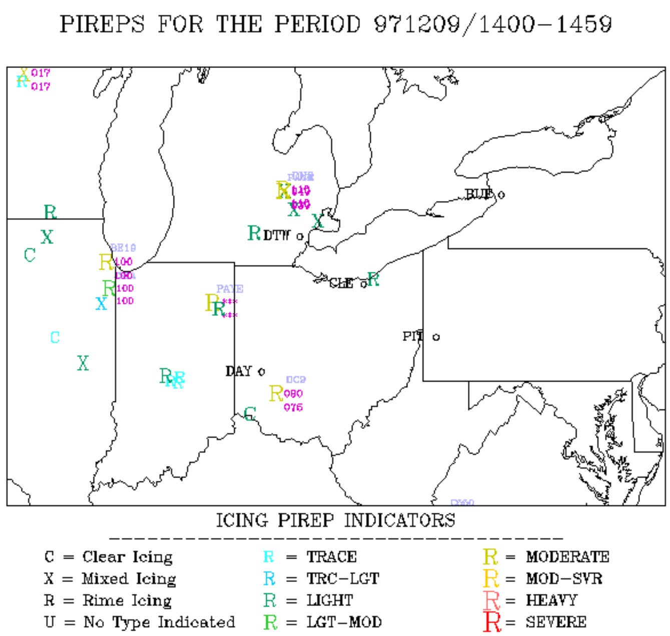
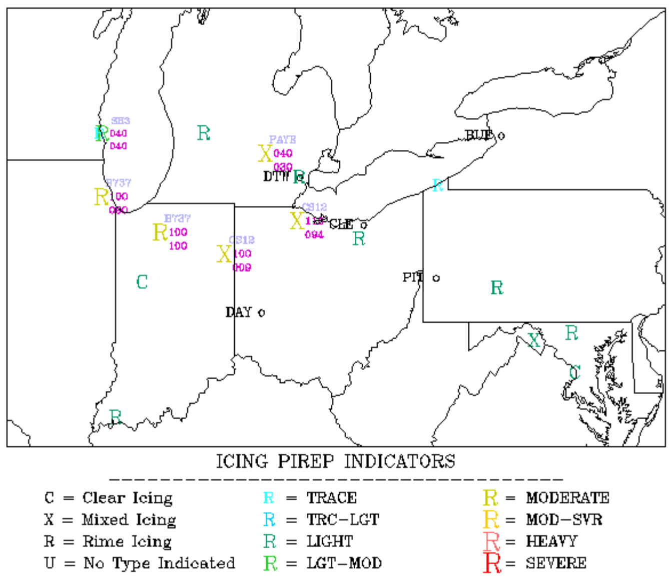


Figure 6 – Pilot reports of icing for 971209, a) 1300-1359 and b) 1400-1459 UTC.

PIREPS FOR THE PERIOD 971209/1500-1559



PIREPS FOR THE PERIOD 971209/1600-1659

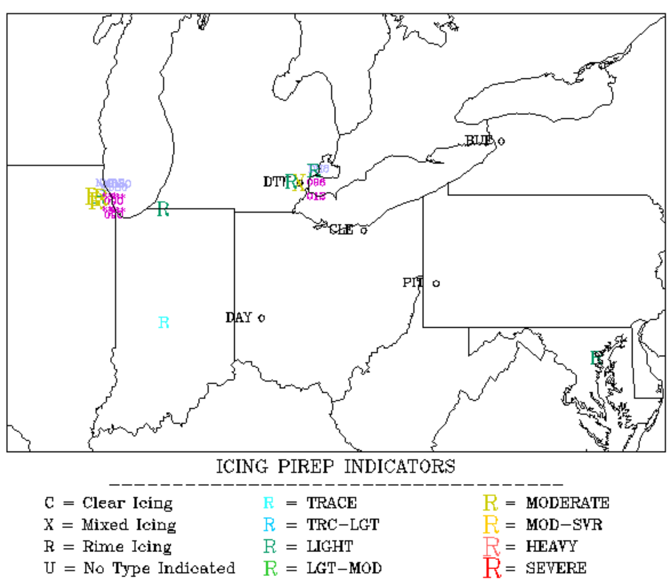
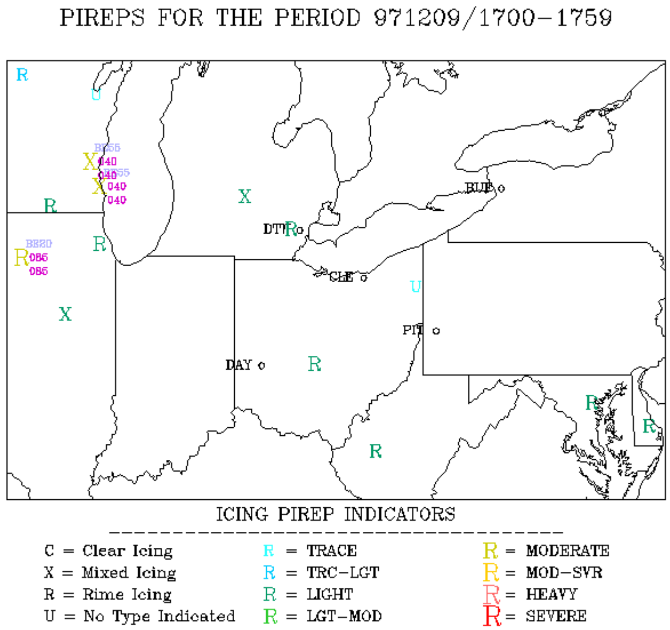


Figure 6 – Pilot reports of icing for 971209, c) 1500-1559 and d) 1600-1659 UTC.



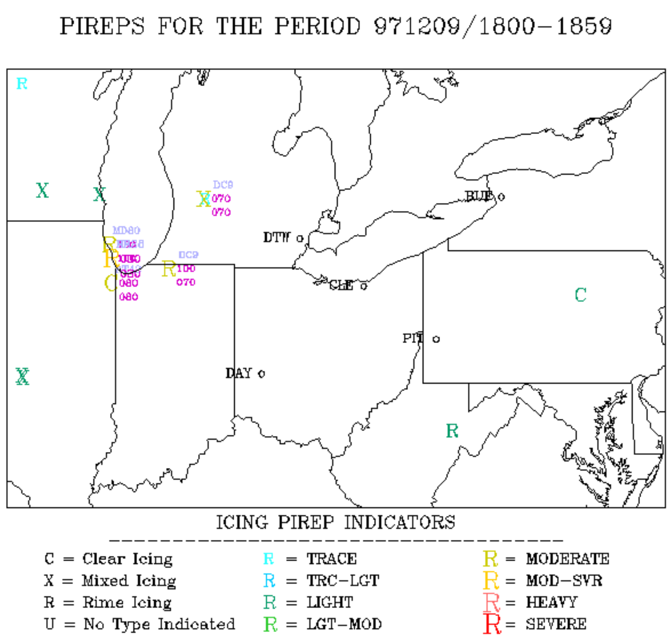


Figure 6 – Pilot reports of icing for 971209, e) 1700-1759 and f) 1800-1859 UTC.

December 11, 1997

Flight #1—Over Cleveland, Youngstown, and Canton-Akron, OH, from 1341 to 1540 UTC.
Flight #2—Over Canton-Akron, Youngstown, OH, and Franklin, PA, from 1628 to 1818 UTC.

Brief overview

Two flights were made on this day into freezing drizzle (ZL), small droplets, and light snow downwind of Lake Erie. The first flight began with climbout through light snow and ZL over Cleveland. The ZL decreased in size with height, and was mostly confined to below 3000' there. Multiple cloud decks existed over Cleveland, with the lowest bases at 2000', and LWC fluctuating between 0.0 and 0.75 (maximum found at 4300', T=-7C). A distinct cloud top was found at 8000', with a CTT of –9C. Dendritic and stellar crystals were observed in the dry layer from 8000' up to the next cloud base. The upper cloud layer extended from 9200' to 11500', contained a bit of in-focus ZL near it's base, a mixture of crystals and small-drops throughout, and LWC up to 0.55 at its top (CTT = -14.5C). The Twin Otter descended into Youngstown (YNG), finding a similar structure, but a deeper dry layer extending from 9700' down to 7200' (1300' deeper), CTT of –8C for the lower cloud deck, and fewer crystals within it. Just below cloud top, LWC was ~0.25, and the droplets were small. LWC decreased, but droplet size increased at lower altitudes, and in-focus ZL was evident from about 4000' down to the surface. LWC was 0.0-0.2 in the ZL, and some columns were mixed in. A series of southwest-to-northeast transects at 500' and 1000' intervals over and to the southwest of YNG echoed this pattern. During level-flight legs between YNG and about halfway toward Canton-Akron (CAK), drop sizes decreased and LWC increased toward the southwest. Close inspection of satellite imagery and wind trajectories seem to indicate that YNG was downstream of winds that had a long fetch over Lake Erie, while CAK was not. An additional aircraft sounding through 12000' indicated that the same structure seen earlier persisted over YNG. One final leg was made to CAK at 4000' before landing there. The ZL seemed to disappear on approach to CAK, but some ZL, mixed with ice crystals, was observed upon landing.

The second flight was made to gather a second sample over YNG, while continuing toward Franklin PA (FKL). Some very small ZL may have been present, but mostly mixed conditions were sampled between CAK and YNG. Only snow was observed during a missed approach to YNG at 1654 UTC. Mixed conditions existed near FKL, with LWC that fluctuated between 0.0 and 0.5 at altitudes between 2000' and 4000'. The clouds in that area appeared to be rather discontinuous. During the return to Cleveland, waves of LWC of 0.1-0.4 and mixed conditions were observed north of YNG. The LWC was markedly lower to the southwest of Cleveland, and light snow was falling when the Twin Otter landed there.

Relevant weather features

At 1200 UTC, there was an elongated 300 mb trough extending from New Mexico to Lake Superior, with a 130 knot jet to its southeast, from Texas to New Jersey (Fig. 1). Central Ohio was on the northern edge of the jet, but no jet dynamics were evident and conditions were dry across the forecast area at this level. Dry conditions persisted at 500 mb, where the trough axis was positioned further to the southeast, extending across northwestern Pennsylvania, northern Ohio, and northern Indiana. Weak cold advection was present over Ohio and Michigan. At 700 mb, a weak low was evident over the northwestern tip of Pennsylvania, with troughs running to the southwest across northern Ohio to central Texas, as well as to the east-northeast across New York state. A strong wind shift was evident across the western trough, especially in northern Ohio. Saturated air was primarily present in swath to its northwest and over northeastern Ohio, close to the low center, where temperatures were approximately -10C. Weak cold advection was evident across Ohio and Indiana, while a pocket of weak warm advections was found over Michigan and southeastern Ontario. The weak low, trough, and wind shift were again present across northeastern Ohio at 850 mb. Dry air and warm advection were present to the immediate west of the low, across Michigan and southeastern Ontario. The warm advection was due to northeasterly winds coming from a narrow thermal ridge to the northwest of the low. Widespread cold advection and moisture were present to the southeast of the trough axis. Northeastern Ohio was located in a transition between the moisture and cold advection to the southeast and the dry air and warm advection to the north and northwest.

The surface map for 0900 UTC (Fig. 2 - 1200 UTC was not available) indicated a weak, 1007 mb low over northwestern Pennsylvania, with a trough running southwestward across Ohio. Freezing drizzle was being reported immediately behind the trough, across northeastern Ohio and near Buffalo. Snow was falling just to the north, at Erie PA and along the northern shore of Lake Erie. By 1500 UTC, the snow crept into northeastern Ohio, changing the precipitation to all-snow at Cleveland. Still, freezing drizzle continued at Youngstown and Franklin PA. By 1800 UTC the snow had taken over northeastern Ohio and northwestern Pennsylvania, and the freezing drizzle ended there. The initially weak low over northwestern Pennsylvania weakened further (to ~1010 mb) during this period.

The satellite imagery for 1415 UTC (Fig. 3) showed widespread cloud across Ohio and Pennsylvania, with CTTs of -10C across the southwestern 3/4 of Ohio, and -15C or so across northeastern Ohio and western Pennsylvania, over and downwind of Lake Erie. Close inspection of the infrared data indicated slightly colder CTTs (-16C) over and northwest of Cleveland (where snow was occurring), compared to those over Youngstown (-14C - where mostly freezing drizzle was occurring). These slightly colder CTTs moved southeast to Youngstown and Franklin with time and roughly matched the changeover from freezing drizzle to snow there (see Fig. 7). Radar data from the Cleveland NEXRAD (not shown, radar mosaic data was only available through 1400 UTC – Fig. 4) showed that this area of colder CTTs matched the areas of higher reflectivity which were present over Cleveland at 1400 UTC and expanded southeastward to Youngstown by 1600 UTC.

No soundings taken across the forecast area were truly representative of the weather at Youngstown. The Buffalo, Wilmington, and Pittsburgh 1200 UTC soundings (Fig. 5) indicated the presence of a single, liquid cloud deck from ~750 mb to near the surface, with CTTs of -8 to -10C. This deck was similar to the lower cloud deck at Youngstown. Freezing drizzle did occur at Buffalo during the period of interest. The 1200 UTC Detroit sounding showed the presence of some colder cloud (CTTs near -16C) from 10,000 to 13,000 feet, but very dry air between 5,000 and 10,000 feet. The colder clouds there were roughly representative of those over Lake Erie and Cleveland at 1400 UTC.

PIREPs of all intensities, and mostly rime and mixed type, were found between 3,000 and 11,000 feet across western Pennsylvania, Ohio, and near Detroit before ~1400 UTC (Fig. 6). The PIREPs became spotty between 1500 and 1700 UTC, as colder cloud tops and snow took over. A few moderate intensity PIREPs showed up just northwest of Detroit after 1600 UTC, as warmer cloud tops began to appear there.

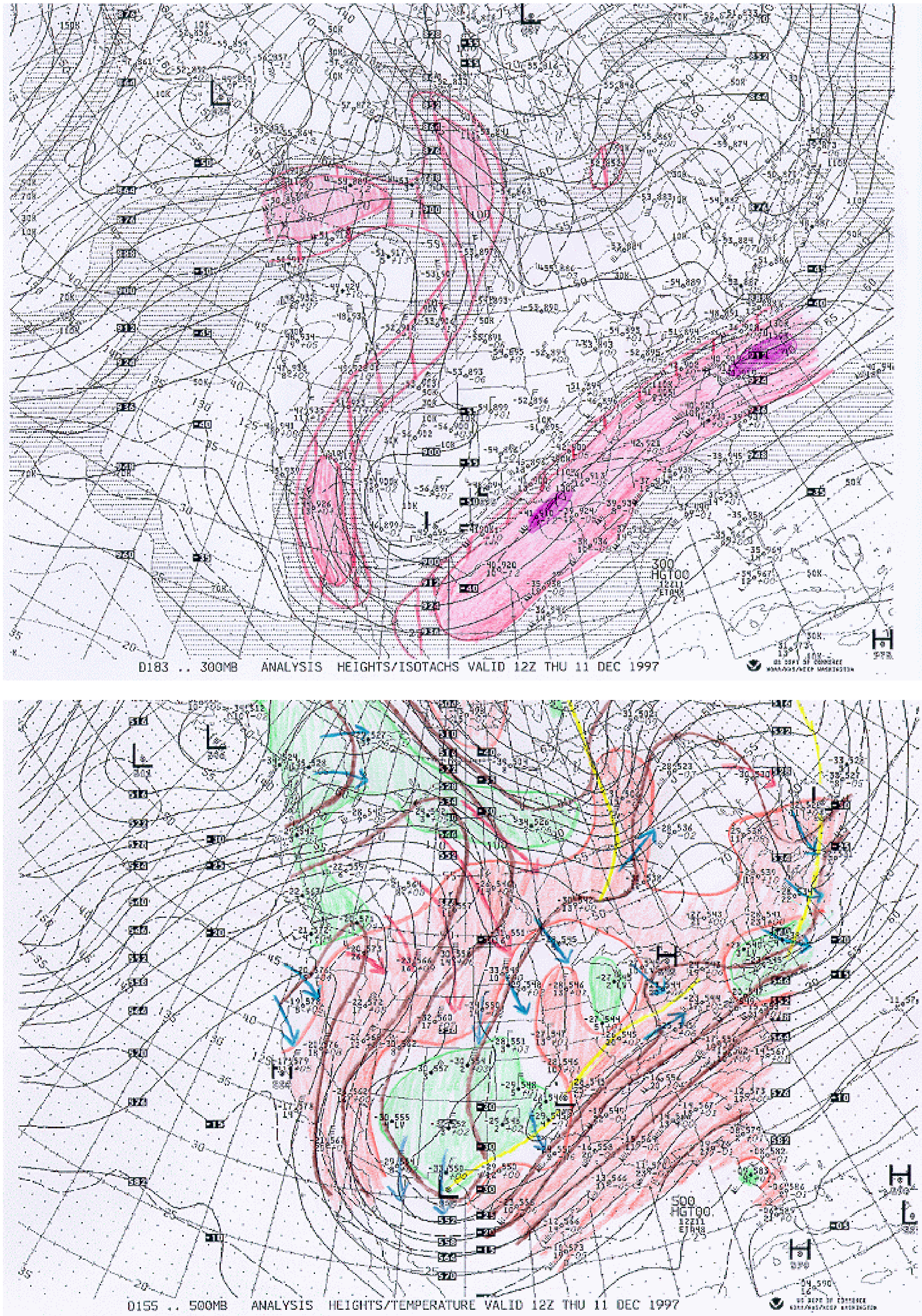


Figure 1 – Upper-air charts for 971211, 1200 UTC at a) 300 and b) 500 mb.

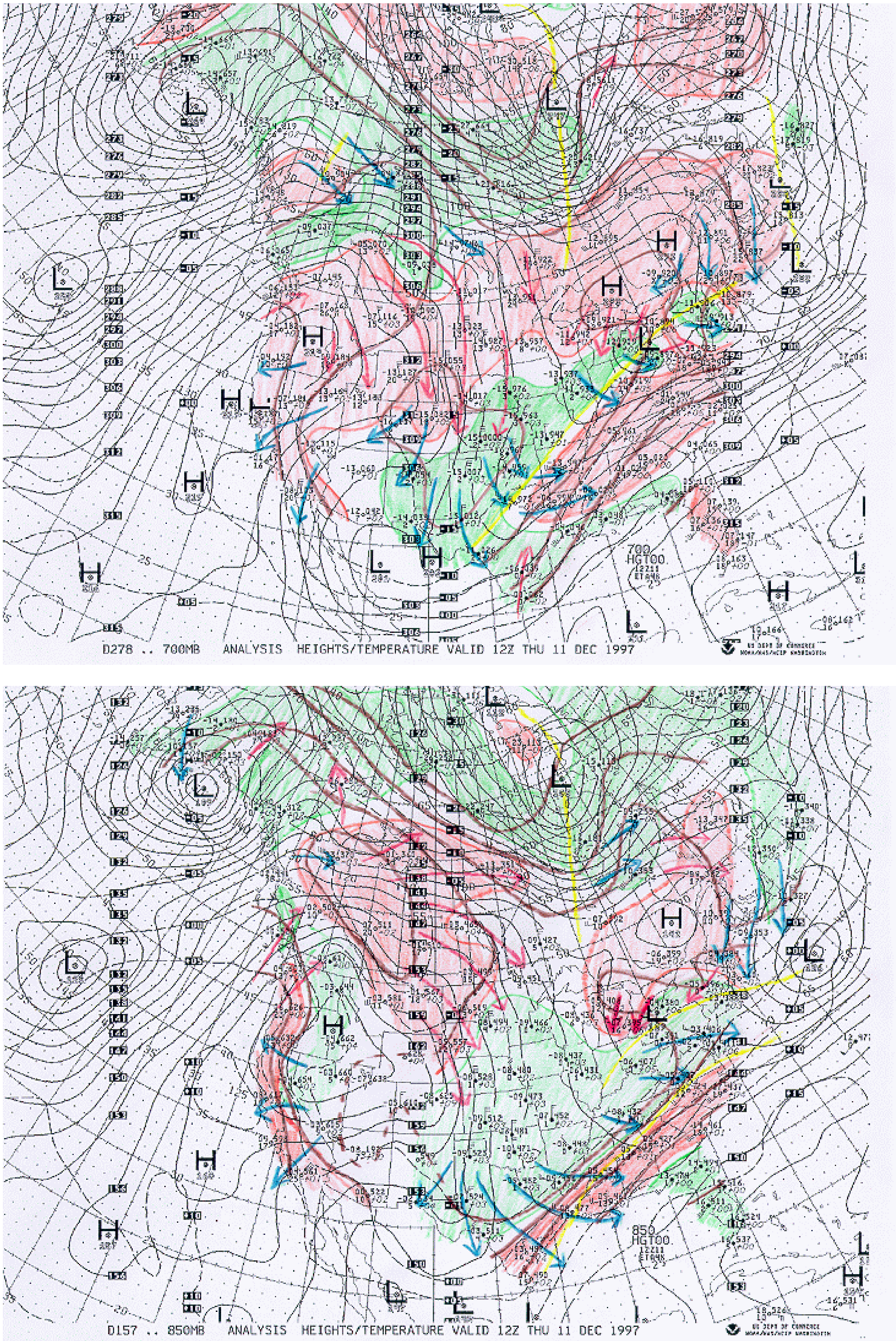


Figure 1 – Upper-air charts for 971211, 1200 UTC at c) 700 and d) 850 mb.

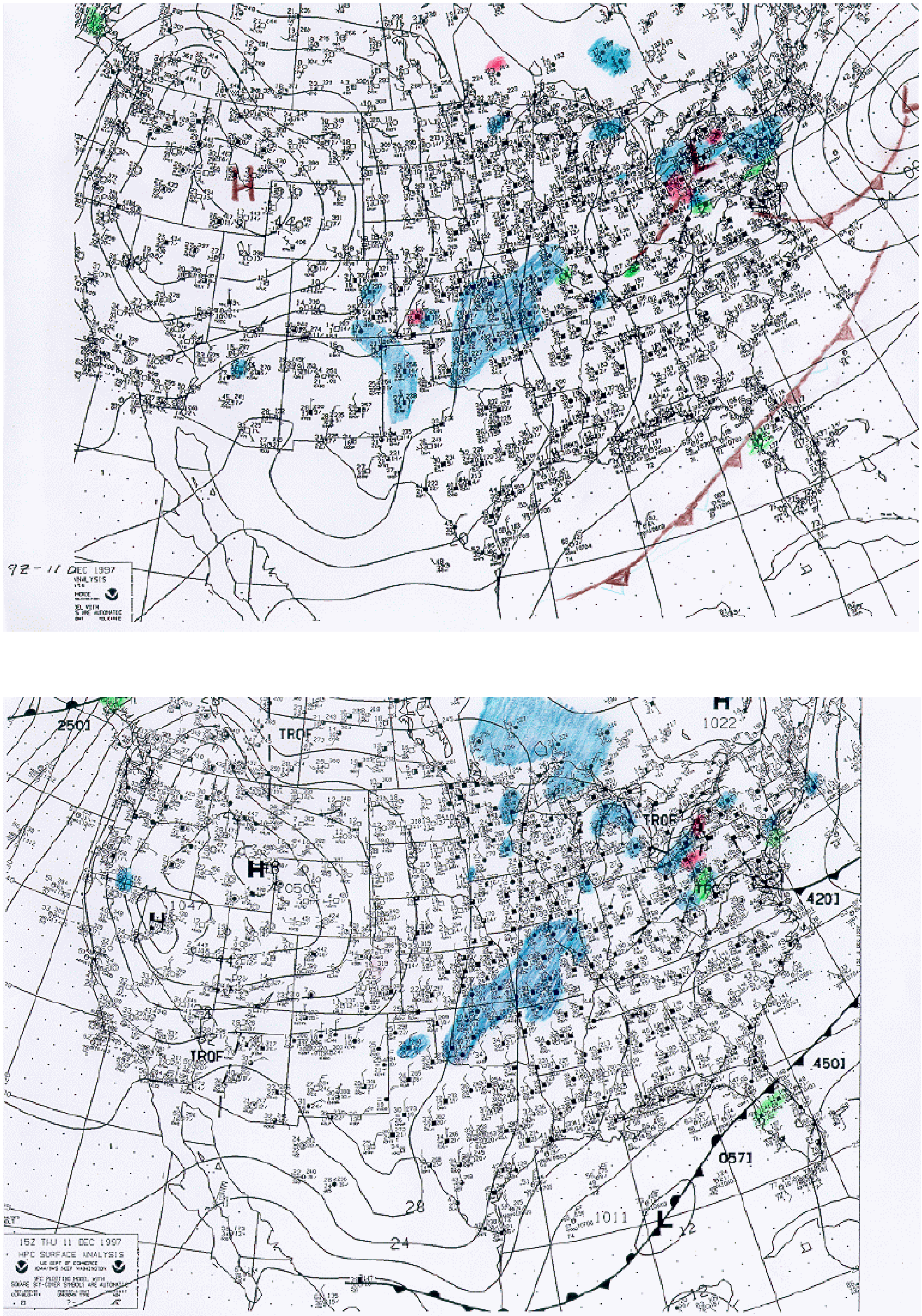
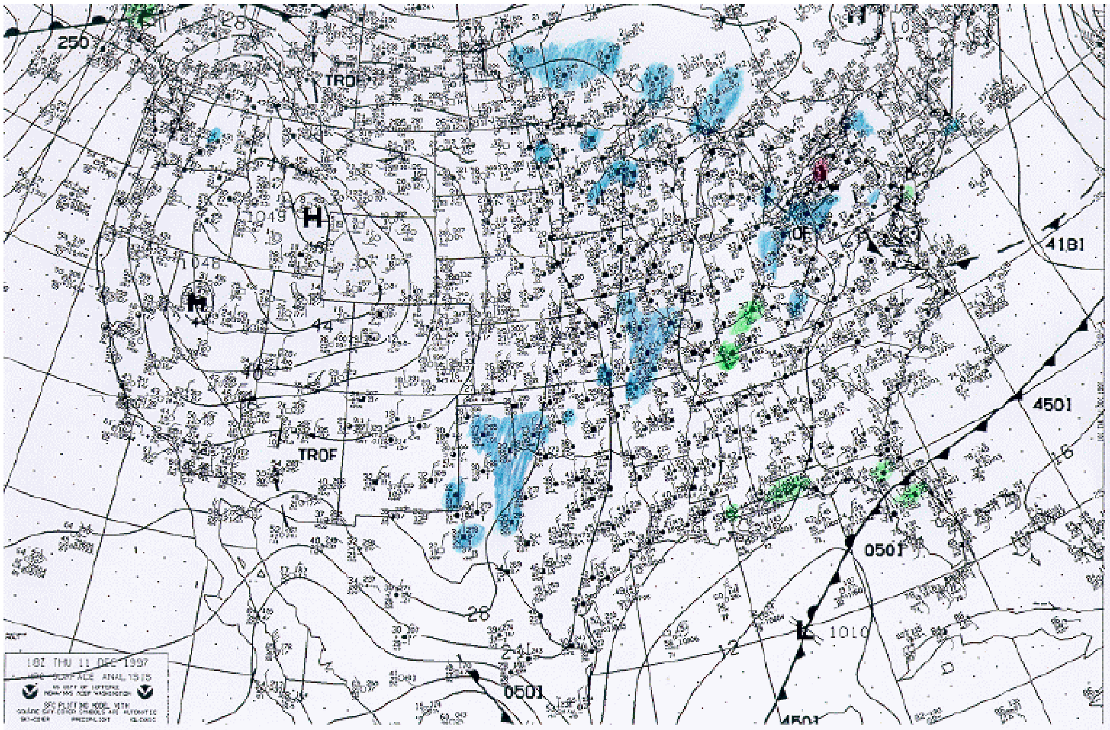


Figure 2 – Surface charts for 971211, a) 0900 and b) 1500 UTC.



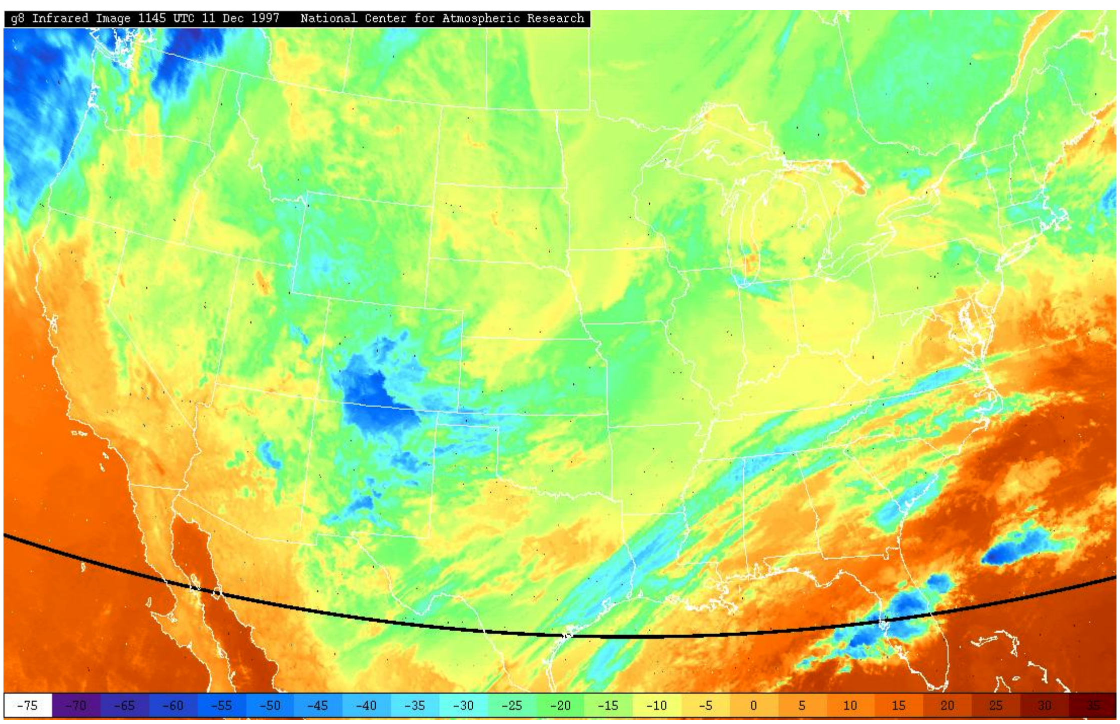
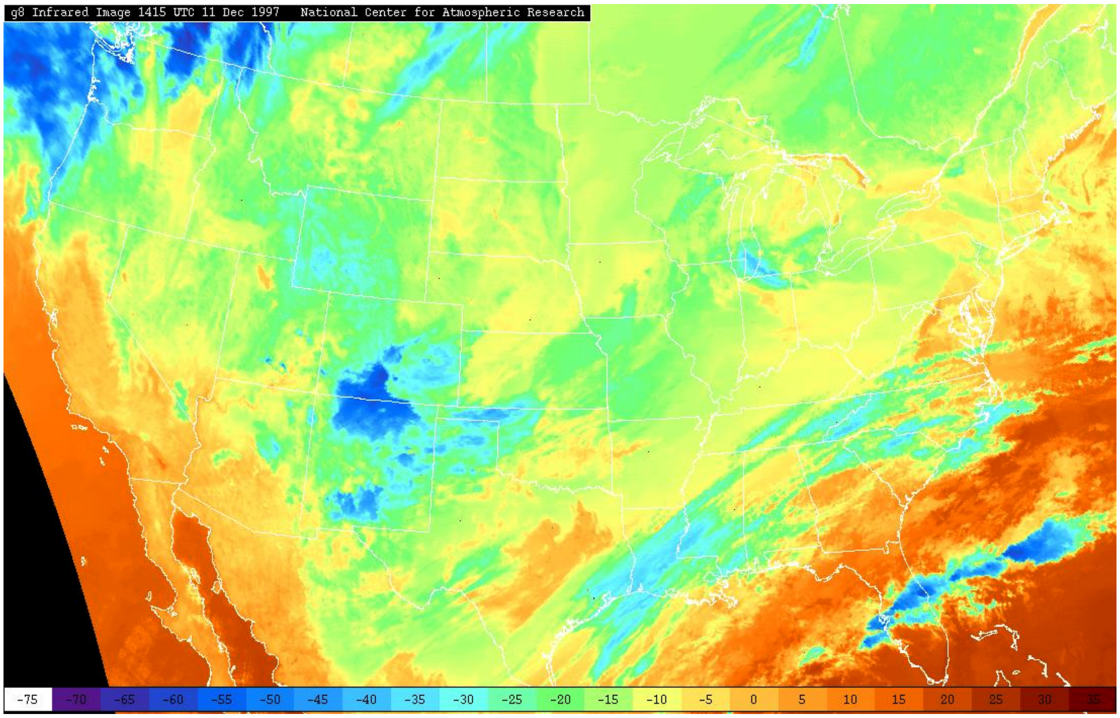


Figure 2 – Surface chart for 971211, c) 1800 UTC.
Figure 3 – GOES-8 a) infrared satellite image for 971211, 1145 UTC.



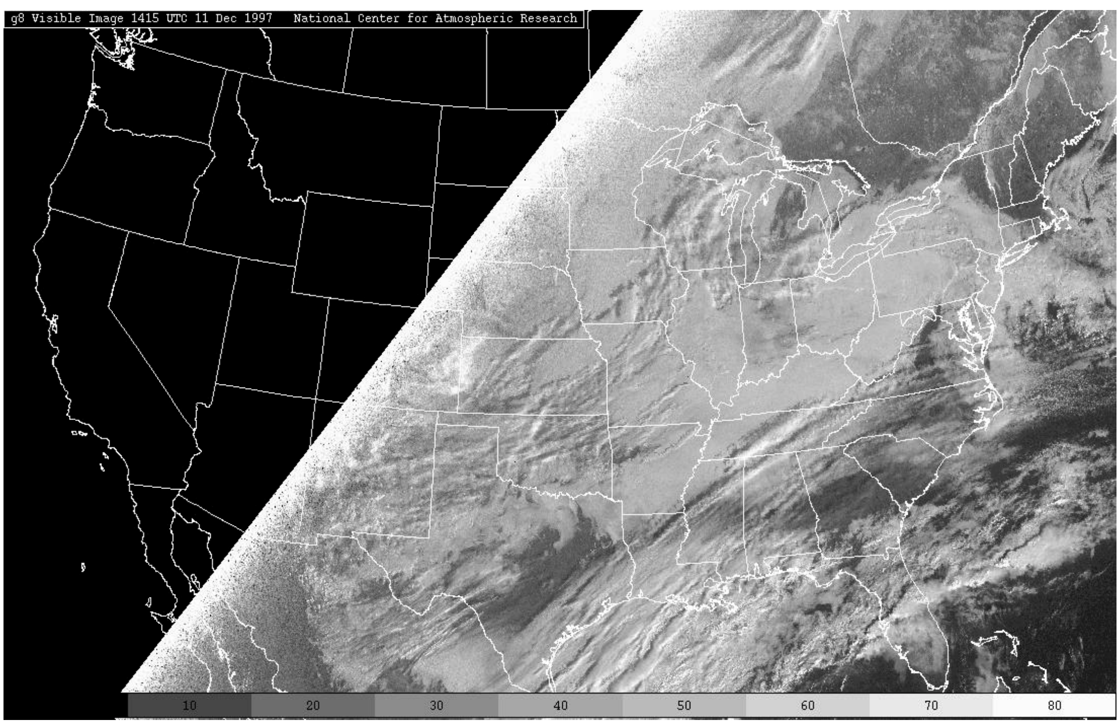
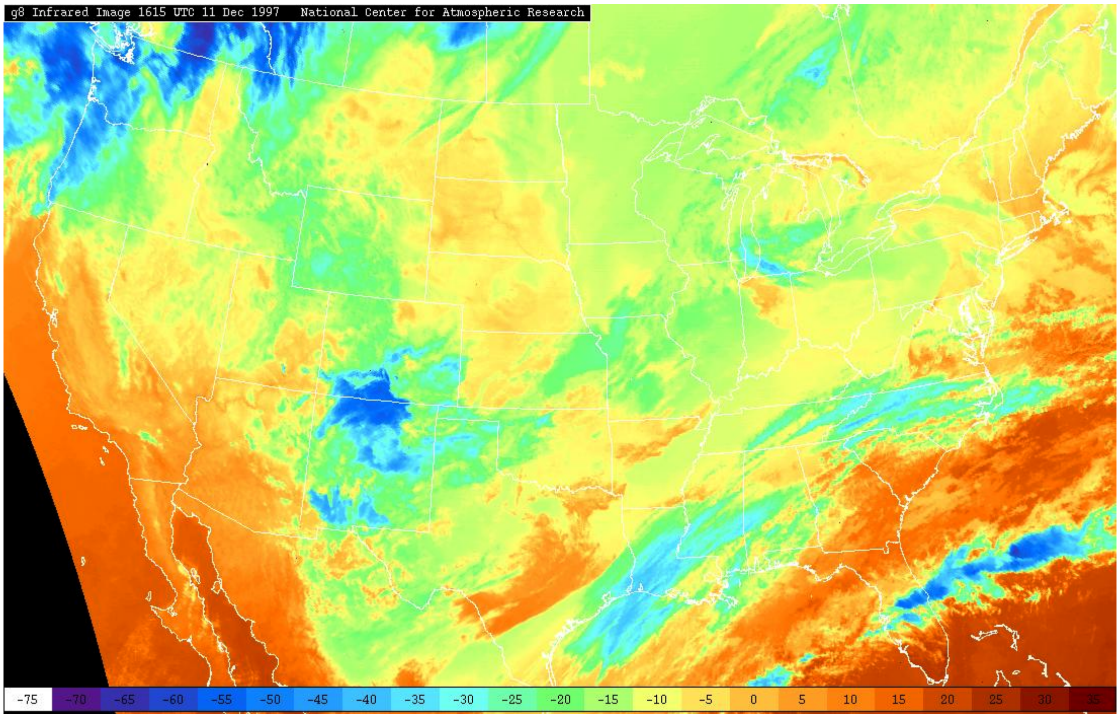


Figure 3 – GOES-8 b) infrared and c) visible satellite images for 971211, 1415 UTC.



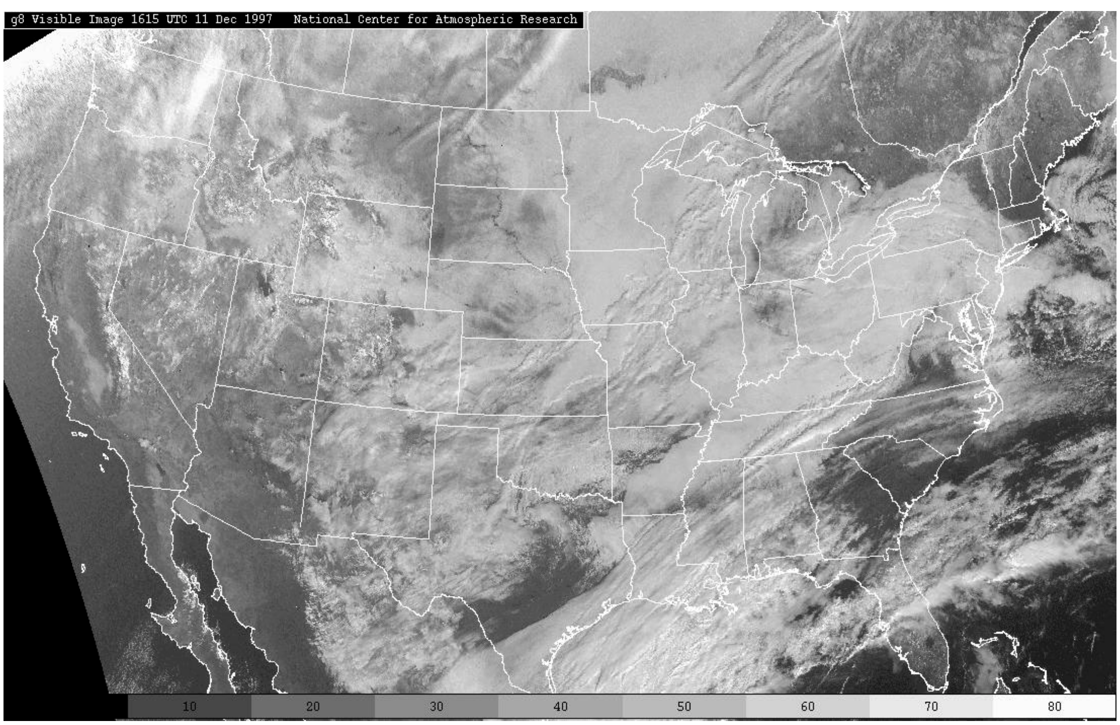
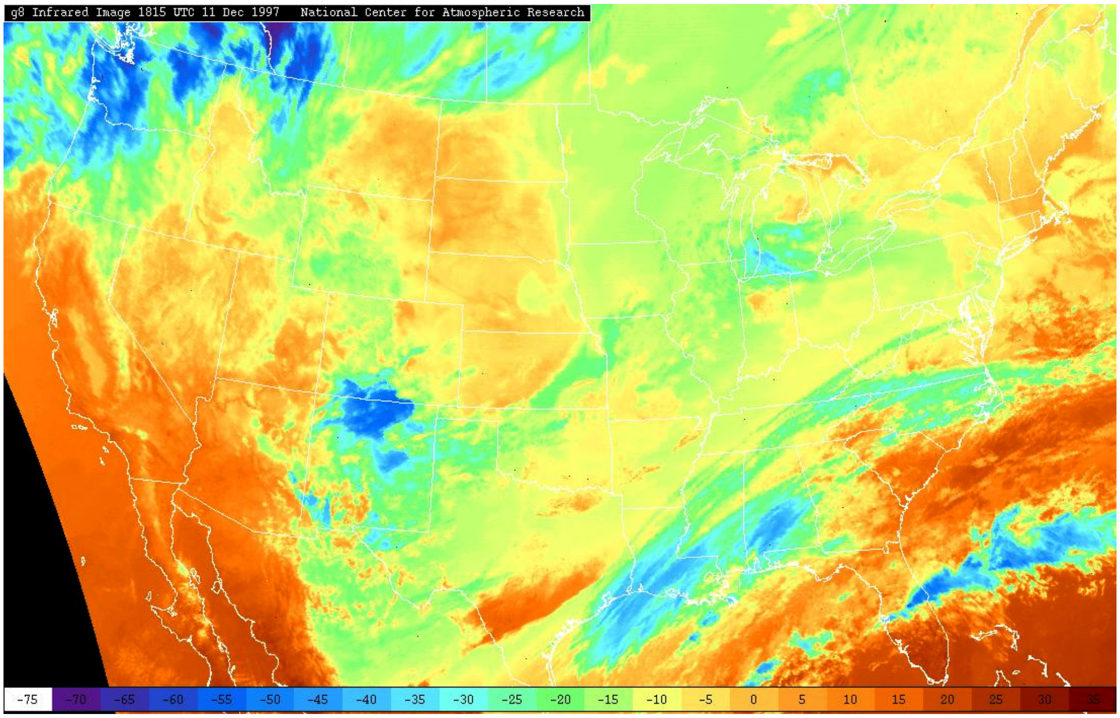


Figure 3 – GOES-8 d) infrared and e) visible satellite images for 971211, 1615 UTC.



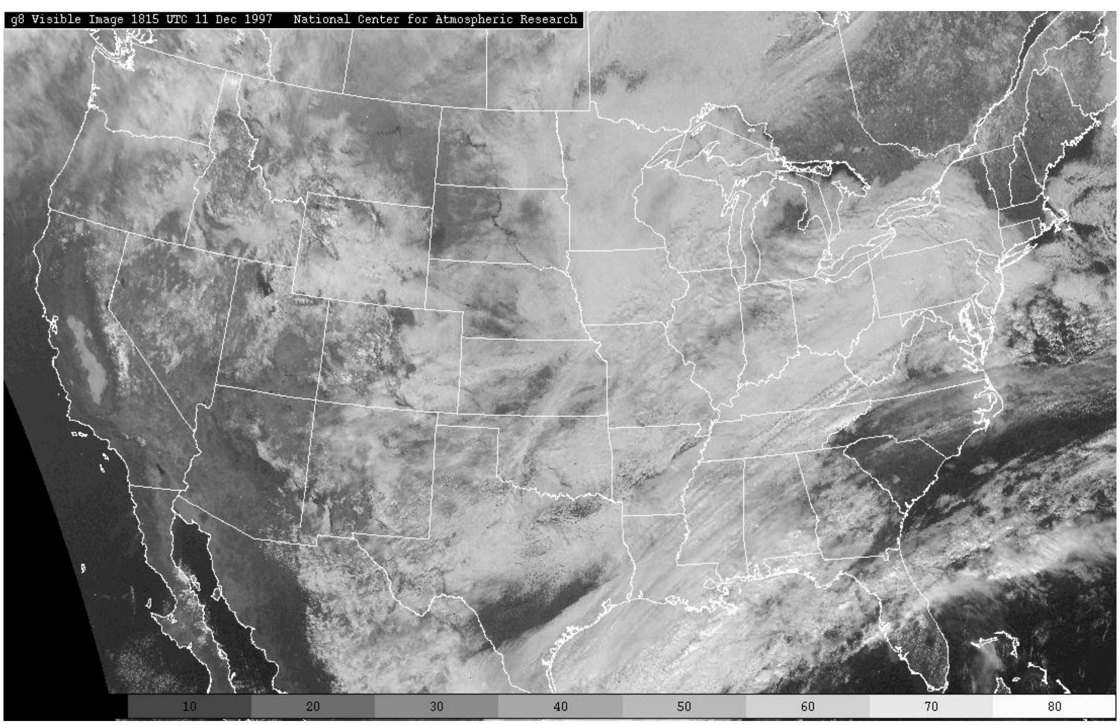
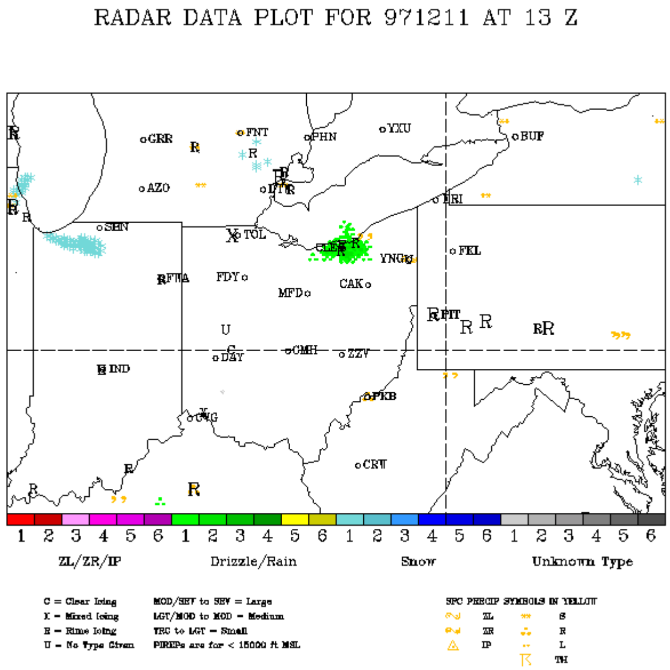


Figure 3 – GOES-8 f) infrared and g) visible satellite images for 971211, 1815 UTC.



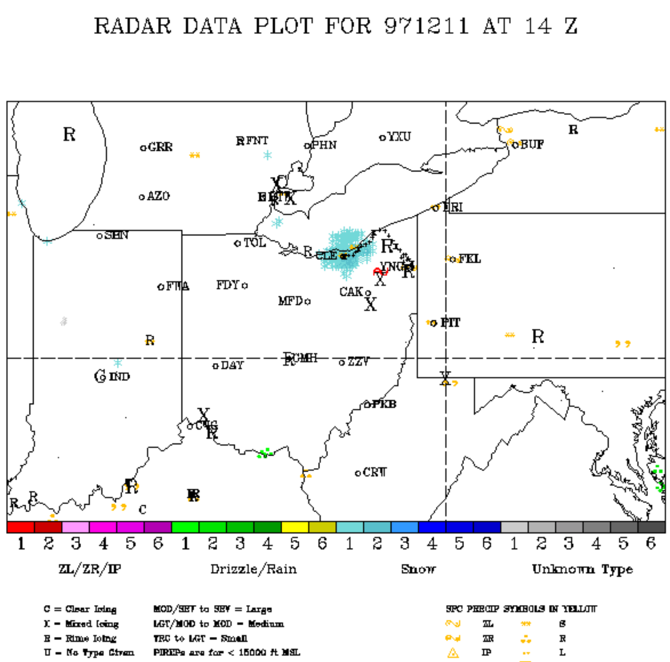
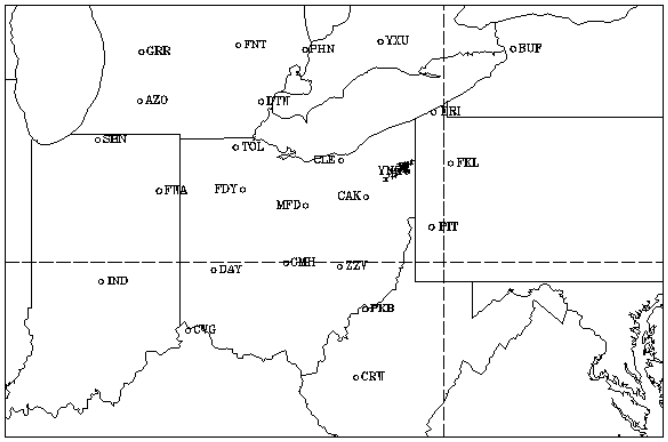


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 971211, a) 1300 and b) 1400 UTC.

AIRCRAFT TRACKS FOR 971211 AT 15 Z



AIRCRAFT TRACKS FOR 971211 AT 16 Z

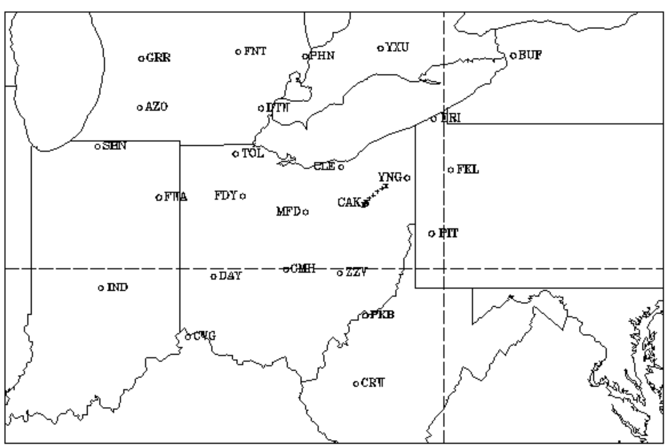
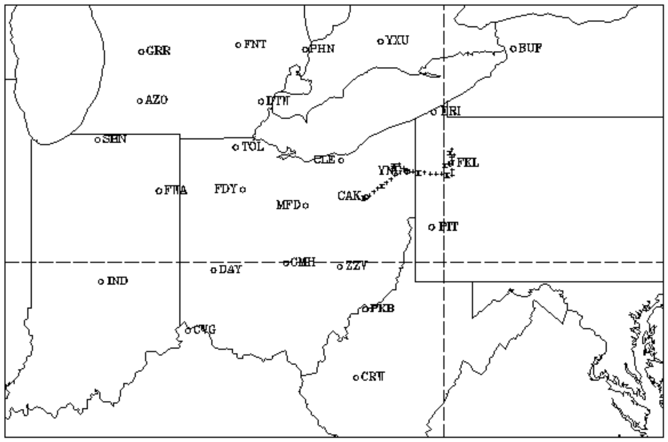


Figure 4 –Twin Otter tracks for 971211, c) 1500 and d) 1600 UTC.

AIRCRAFT TRACKS FOR 971211 AT 17 Z



AIRCRAFT TRACKS FOR 971211 AT 18 Z

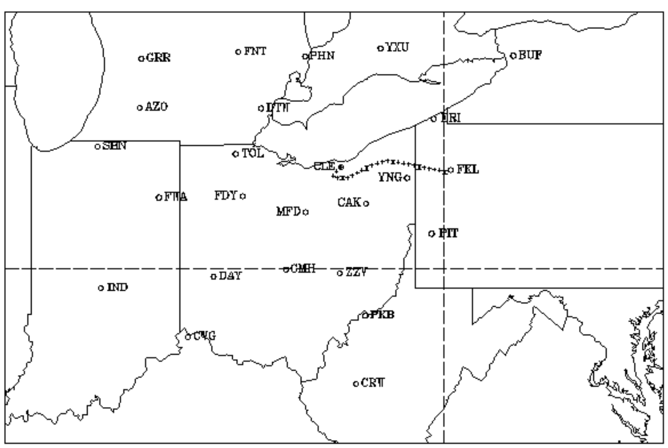
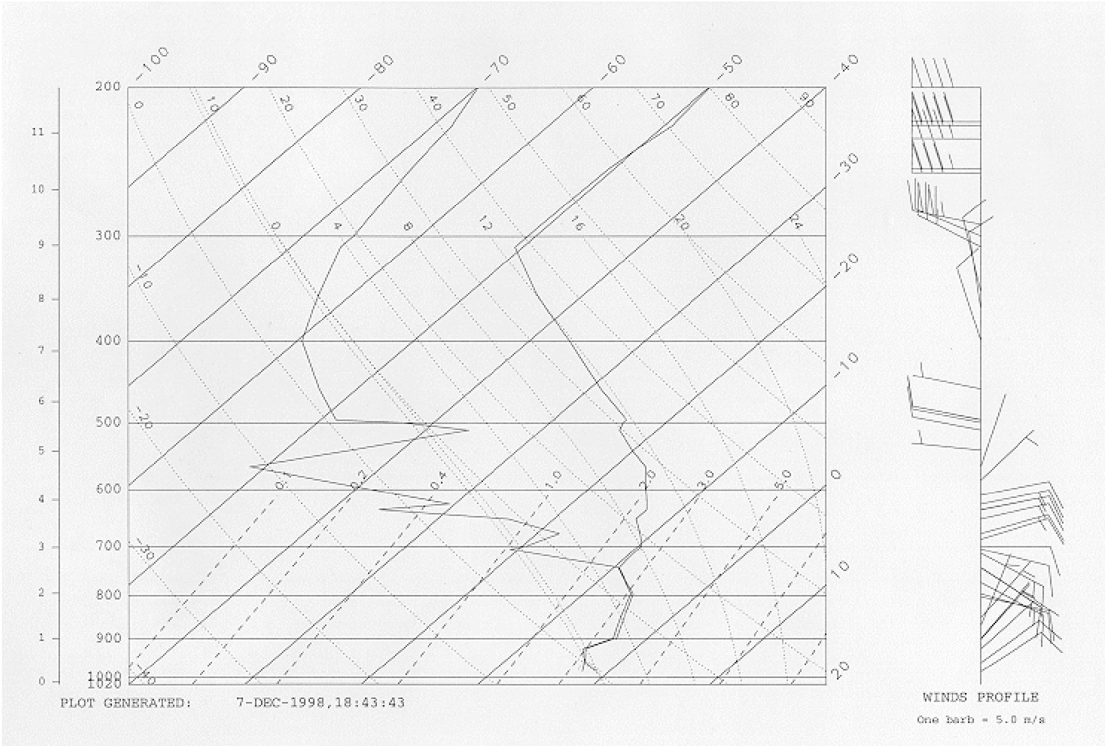


Figure 4 –Twin Otter tracks for 971211, e) 1700 and f) 1800 UTC.



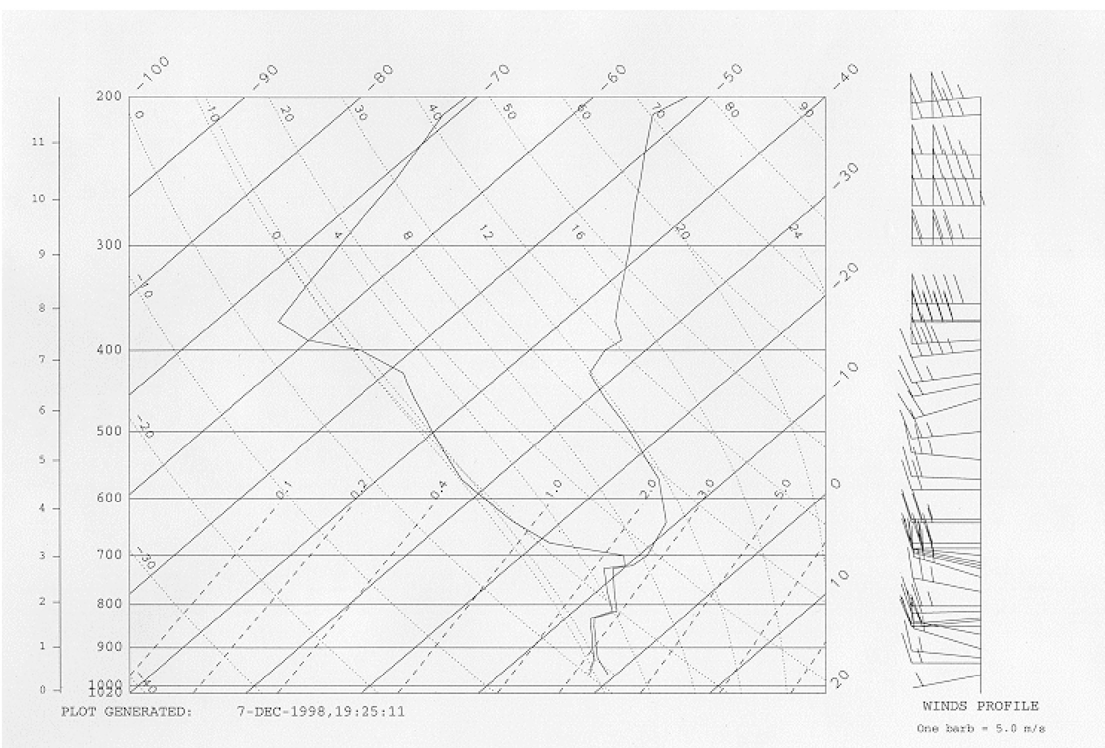


Figure 5 – Balloon-borne soundings from a) Buffalo and b) Pittsburgh for 971211, 1200 UTC.

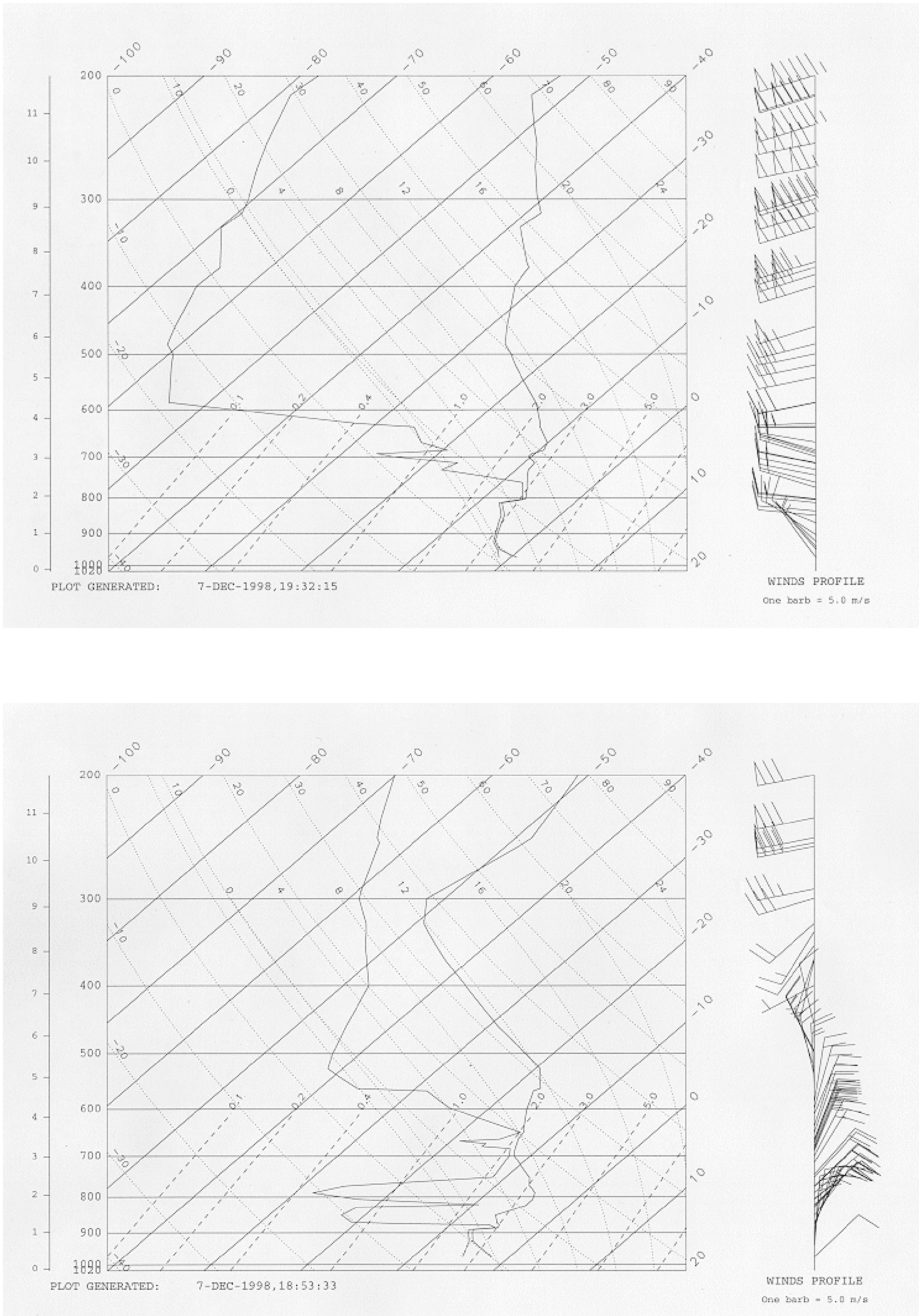
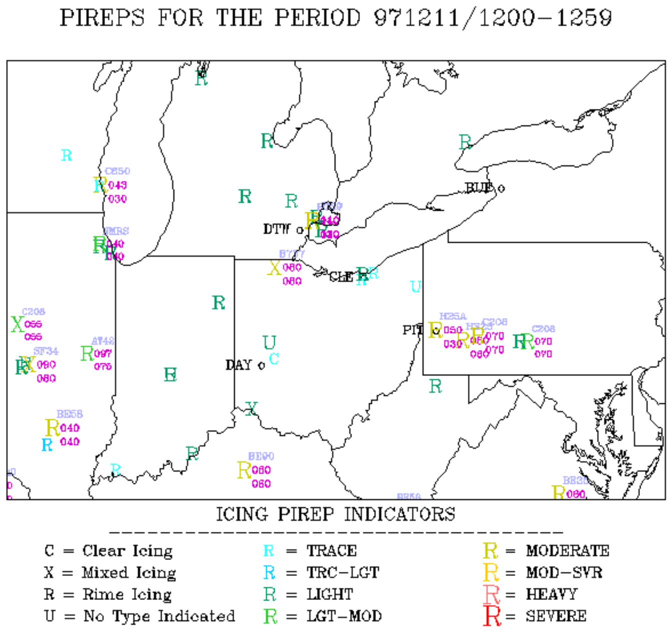


Figure 5 – Balloon-borne soundings from c) Wilmington and d) Detroit for 971211, 1200 UTC.



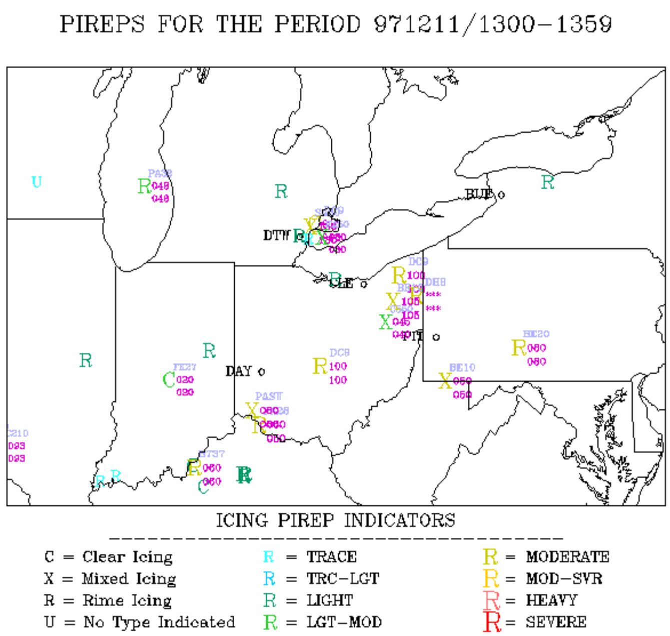
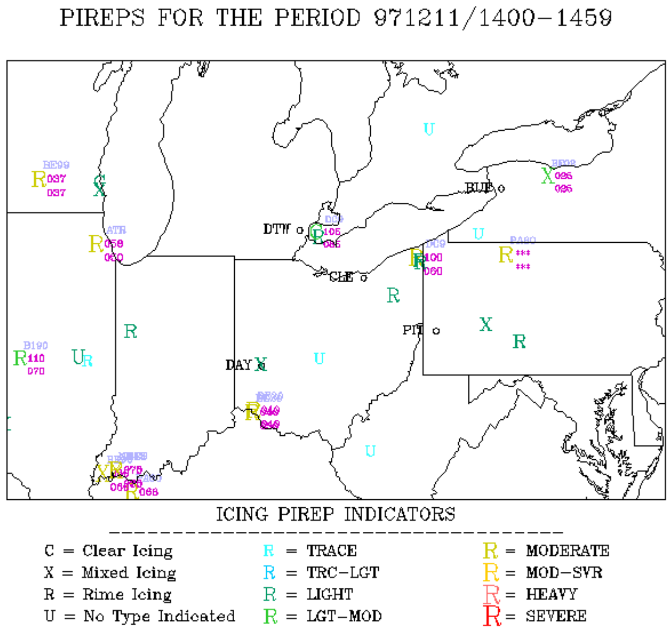


Figure 6 – Pilot reports of icing for 971211, a) 1200-1259 and b) 1300-1359 UTC.



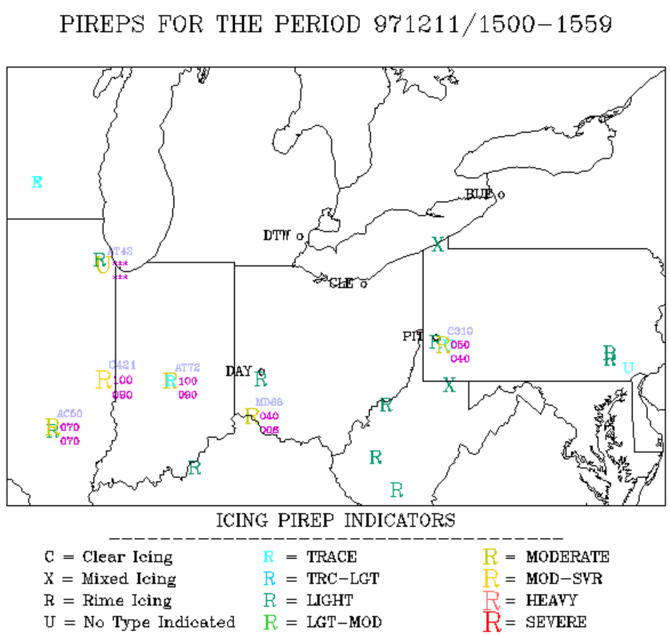
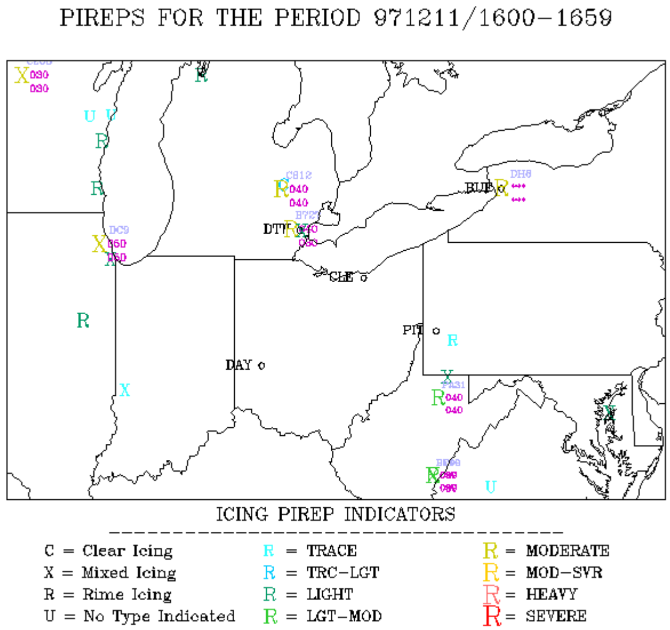


Figure 6 – Pilot reports of icing for 971211, c) 1400-1459 and d) 1500-1559 UTC.



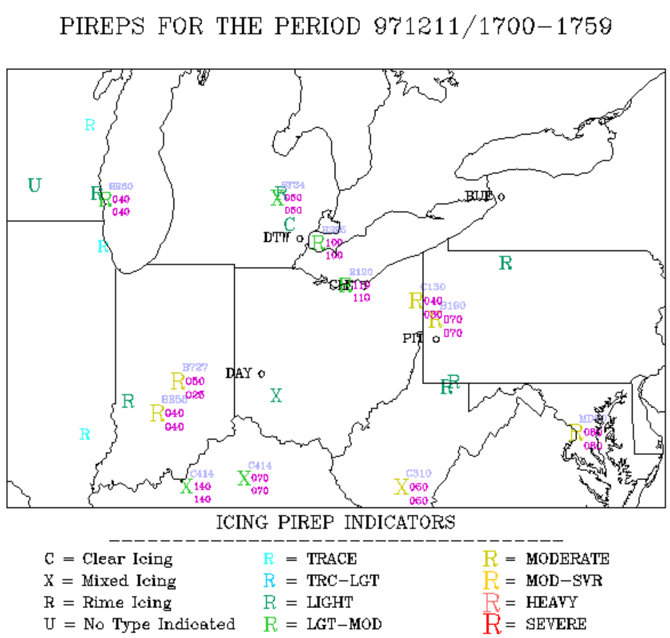
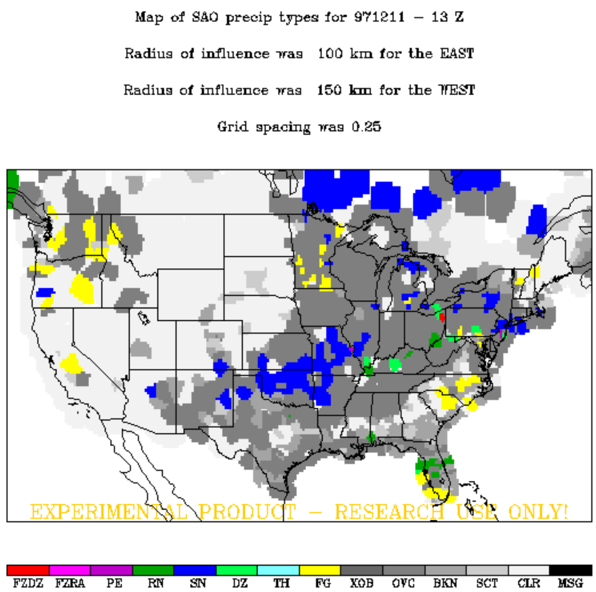


Figure 6 – Pilot reports of icing for 971211, e) 1600-1659 and f) 1700-1759 UTC.



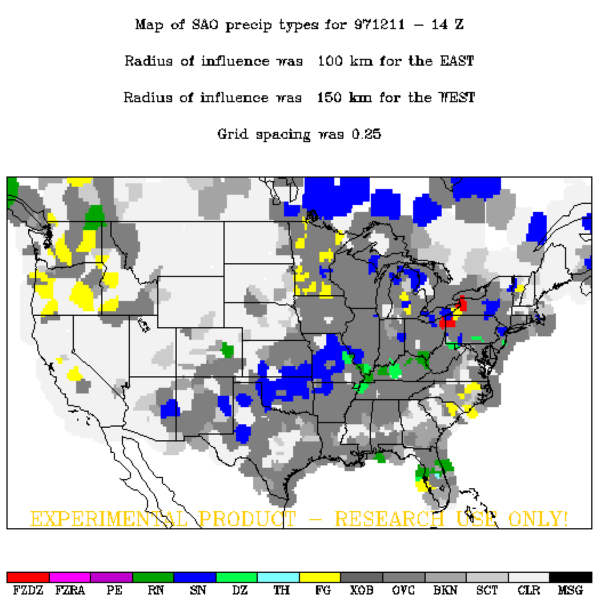
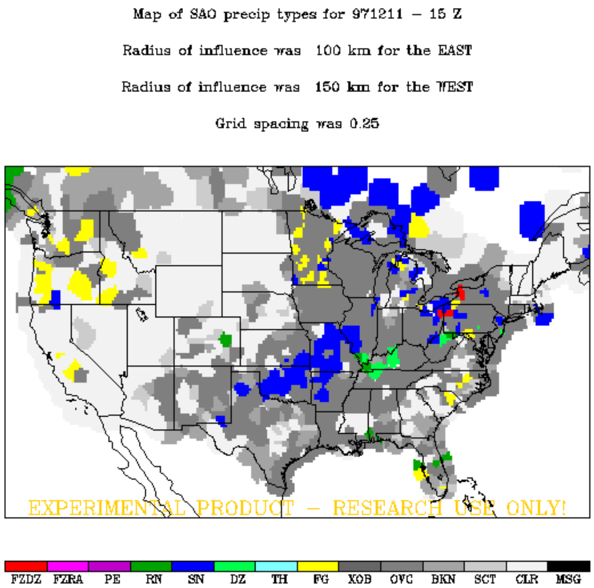


Figure 7 – Surface observations of precipitation type and cloud cover for 971211, a) 1300 and b) 1400 UTC.



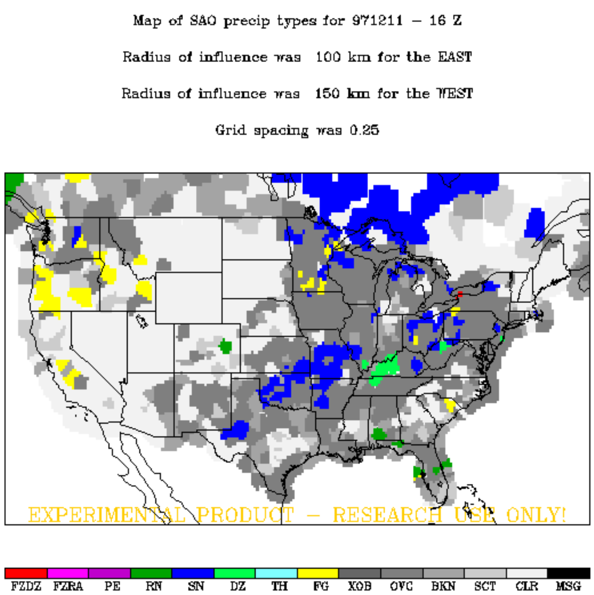
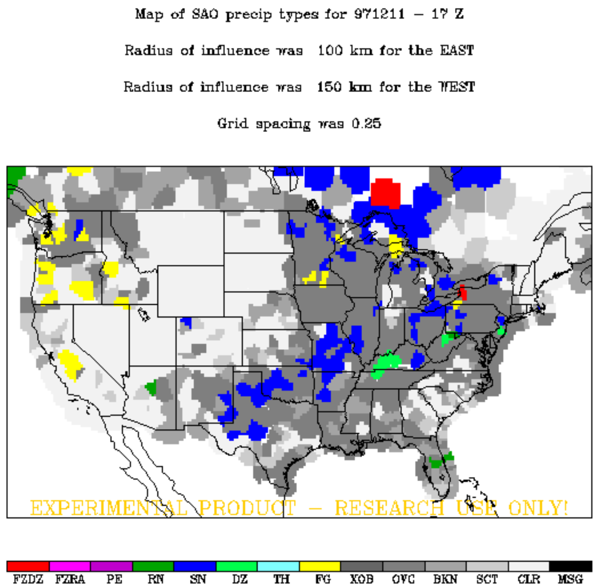


Figure 7 – Surface observations of precipitation type and cloud cover for 971211, c) 1500 and d) 1600 UTC.



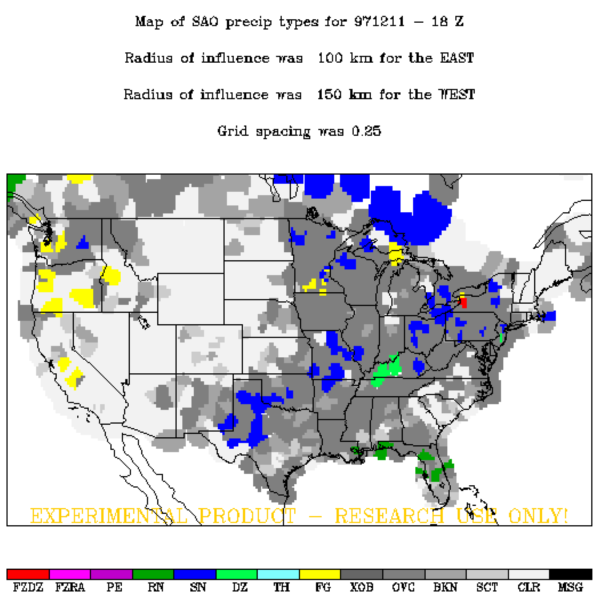


Figure 7 – Surface observations of precipitation type and cloud cover for 971211, e) 1700 and f) 1800 UTC.

January 12, 1998

Flight #1—Over Toledo, OH, and South Bend, IN, from 1804 to 2006 UTC.
Flight #2—Over Kalamazoo, MI, and Toledo, OH, from 2114 to 2300 UTC.

Brief overview

Two flights were made on this day. During the first flight, mixed conditions, including a little freezing drizzle (ZL), were observed during climbout from Cleveland. LWC values were as high as 0.7 at the top of the highest clouds (~9000'), where temperatures were near –7C. Somewhat lower LWCs (up to 0.5) and a classical "warm nose" temperature structure were observed over Toledo and South Bend. Temperatures reached +2.5C near 4000', and were slightly below freezing at altitudes below 3000'. Some ZL was found in the lower sub-freezing layer, but ice crystals were not consistently observed above the melting layer, and thus, the ZL may have formed via either the classical or non-classical mechanism. The content of the clouds and precipitation was quite variable, with both mixed-phase and all-water clouds observed in multiple cloud decks.

Initial takeoff during the second flight occurred in drizzle (L) at the surface and ZL aloft. This ZL and L appeared to be caused by the classical mechanism, as the warm nose continued to be present, and light snow was observed above the upper freezing level. Mixed conditions were again observed aloft, and slightly colder ZL (T = -1.5C) that formed via the classical and/or non-classical mechanisms was found below 3000' near Kalamazoo. Signs of both mechanisms were present, with a warm nose structure and pockets of ice crystals aloft, supporting the classical mechanism, while evidence for the non-classical mechanism was seen via gradually increasing drop sizes with decreasing height beginning *above* the warm nose. Some deeper, colder, mixed-phase clouds with LWC up to 0.5 were observed between 10000' and 12000' between Kalamazoo and Toledo around 2200 UTC.

Relevant weather features

At 1200 UTC, a weak 300 mb low/trough ran north-south through the western High Plains, while a small jet core of 90+ knot winds was present on its eastern side (Fig. 1). Another jet maximum was found over Tennessee, but no jet dynamics appeared to affect the forecast area. The 1200 UTC 500 mb chart was not available. At 700 mb, a closed low was situated just north of the Minnesota/North Dakota border, and a weak trough ran from Iowa down to Arkansas. Weak warm advection occurred ahead of his trough, across Indiana and Illinois. Dry conditions existed across these states, but saturated air with temperature near -7C was found the across Ohio. Saturated air and strong warm advection covered the forecast area to the west of Cleveland and Pittsburgh, ahead of an upper-level trough/cold front that was draped across Wisconsin and Iowa.

At 0000 UTC, the 300 mb low had closed off to the north of Minnesota, while the trough/jet pattern moved slightly to the east (Fig. 2). The 500 mb low was located just east of the 300 mb low, had

several closed contours, and a trough which ran southwest from it. Saturated air arced from the mid-Atlantic states through the northern Great Lakes, and back into northern Illinois, while dry air covered the rest of the forecast area. The dry air had not advanced nearly as far at 700 mb, as moist conditions were evident across the area. Warm advection continued ahead of the advancing trough, but still only reached Indiana and western Ohio at this point. The 700 mb low remained closed, and was positioned only slightly to the northeast of the 500 mb low. The 850 mb low also showed this fairly "stacked" structure, but the trough/cold front attached to it had reached Chicago, well ahead of the 700 mb trough location. Strong cold advection was occurring behind the trough, while warm advection and mostly saturated conditions were found ahead of the trough.

Surface charts for the period show a 1026 mb high moving slowly eastward across New England, while a 1015 mb, occluded low deepened to 1009 mb as it moved eastward to Lake Superior (Fig. 3). The occluded front ran southeast into Wisconsin, where it became a cold front that draped back west to Colorado. The cold front progressed southeastward with the low, reaching central Michigan and eastern Indiana by a 0000 UTC. Widespread snow falling behind the front dissipated with time. Areas of freezing drizzle, freezing rain, and ice pellets were found at 1200 UTC from Colorado to Ohio between this front and a weak warm front that extended from Texas into Kentucky. As the cold front advanced, the freezing precipitation ended up behind it. Temperatures rose in Indiana and Ohio, causing the precipitation to change to patchy drizzle and rain there by 1800 UTC. A bit of freezing drizzle and freezing rain popped up in Michigan from 2200 to 0000 UTC, as of the weak warm front moved northward across Indiana.

Sounding data from Lincoln IL, Detroit and Wilmington (Fig. 4) indicated the potential for both classical and non-classical processes over northern Indiana and Ohio during the flight period. This nicely matched the aircraft observations of both mixed-phase and all-water clouds above a warm nose found near 4000'. Some freezing drizzle that appeared to vary in formation mechanism was observed below 3000'. Multiple cloud decks were also evident in several of the balloon-borne soundings.

Radar mosaic data (Fig. 5) clearly demonstrated the spotty nature of the precipitation in the area of the flights. Disorganized pockets of drizzle, rain, freezing drizzle, freezing rain, and even ice pellets were observed across northern Indiana, southern Michigan, and northern Ohio between 1800 and 2300 UTC. Infrared satellite data (Fig. 6) reflected this spotty nature, with pocketed, inconsistent cloud top temperatures (-10C < CTTs < -20C) across the area of flight. However, visible imagery did indicate that the cloud cover was rather widespread. Deeper, colder clouds accompanied the advancing cold front, and brought more efficiently precipitating clouds into western Michigan and northwest Indiana around 2200 UTC. This deeper cloud helped to make the classical freezing rain process become more widespread in southern Michigan toward the end of the day.

Moderate intensity PIREPs (Fig. 7) were very common across the region. Most were mixed in type and occurred at altitudes between 6000 and 12,000 feet, but a few were found below 4000' near the Indiana/Michigan border. Nearly all of the PIREPs were made ahead of the advancing cold/occluded front.

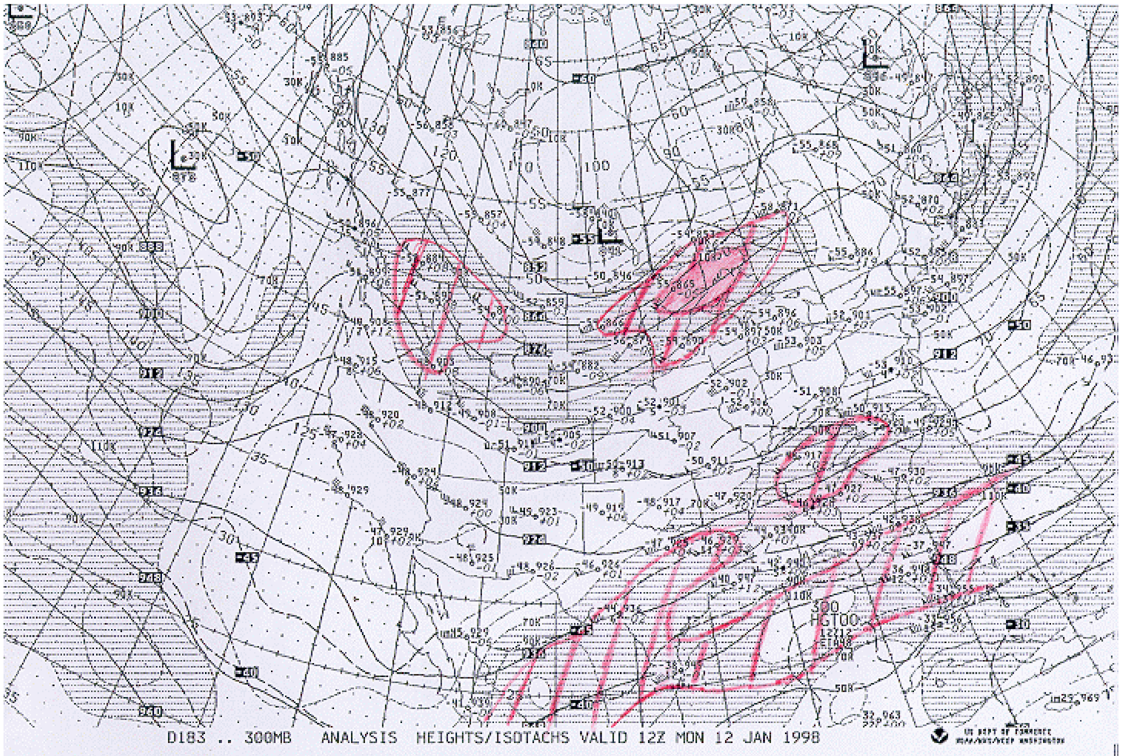


Figure 1 – Upper-air chart for 980112, 1200 UTC at a) 300 mb.

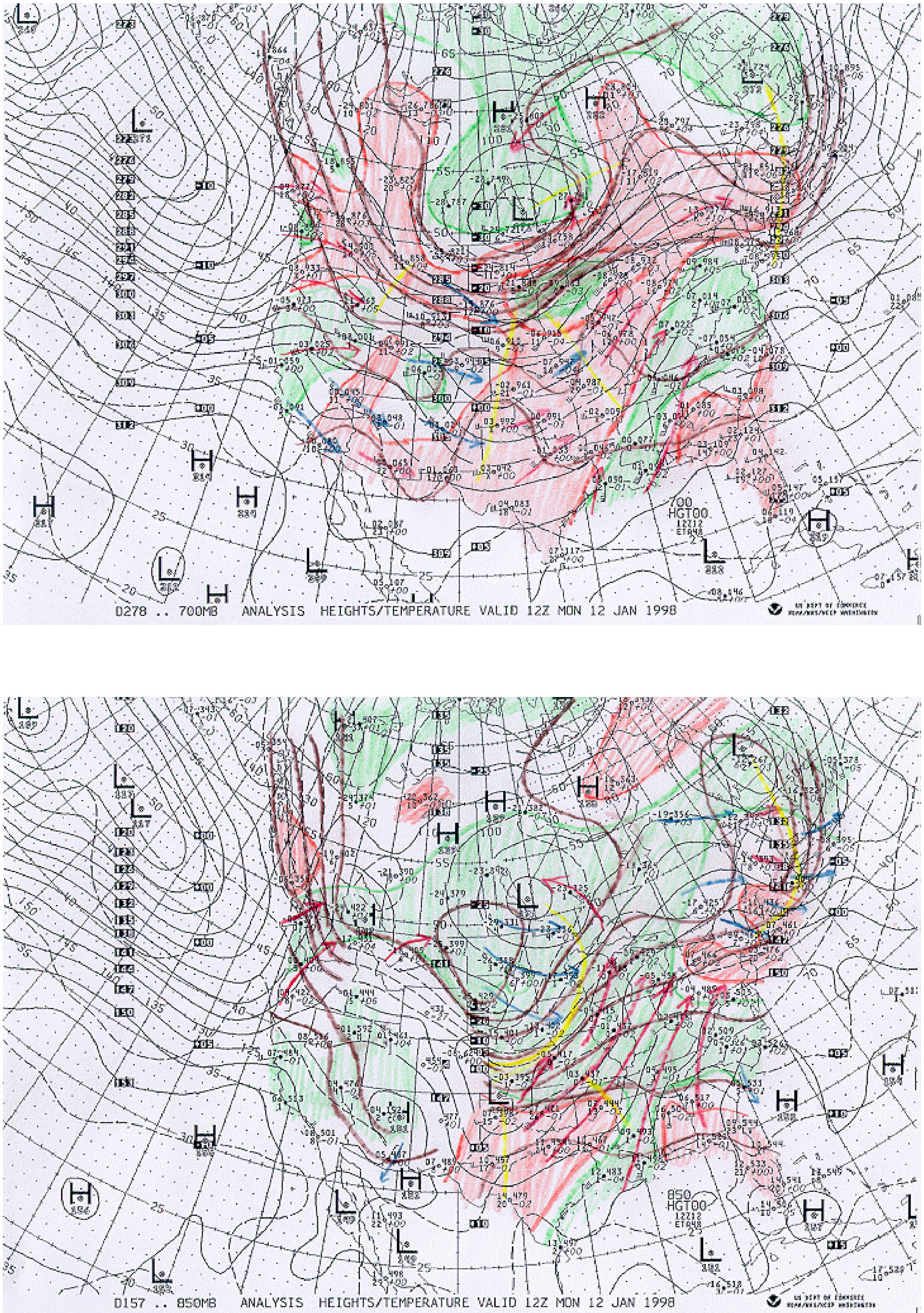
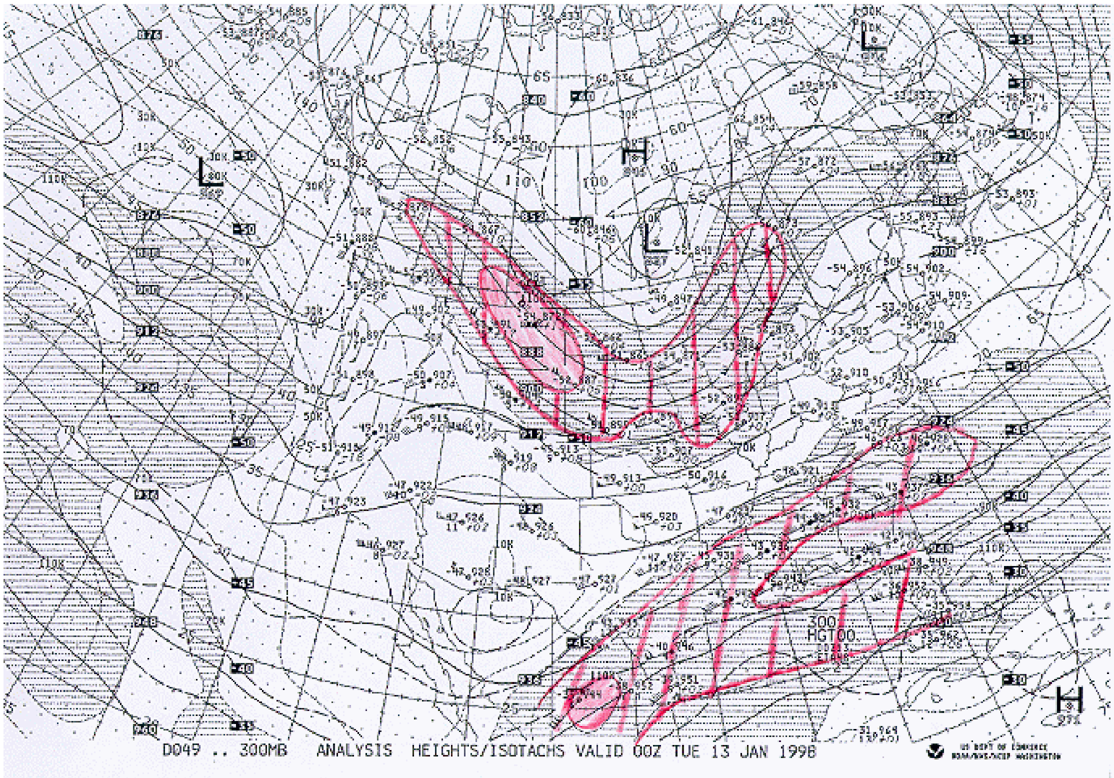


Figure 1 – Upper-air charts for 980112, 1200 UTC at b) 700 and c) 850 mb.



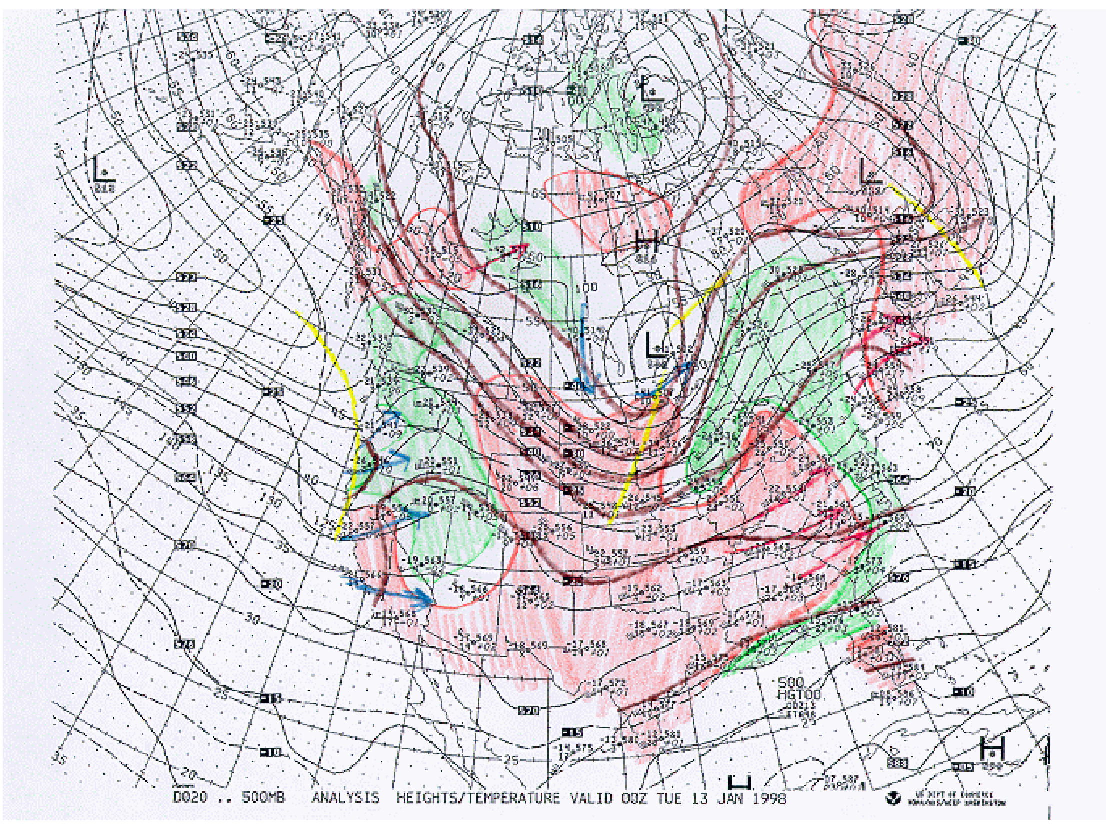
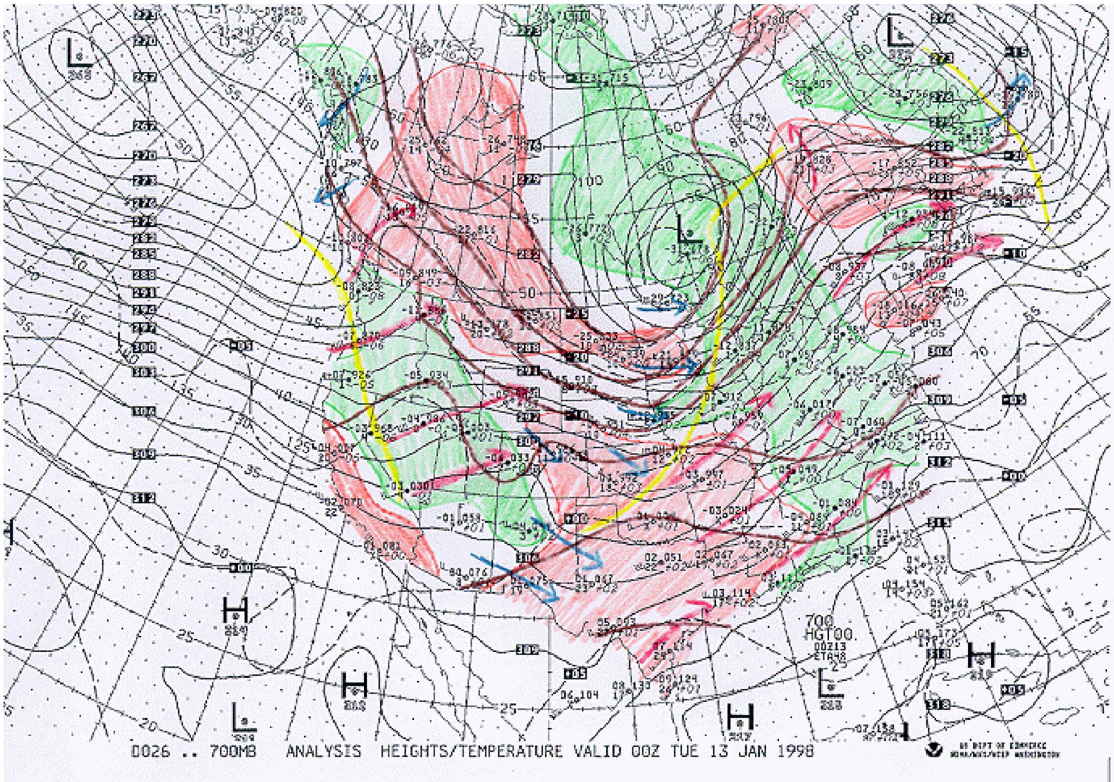


Figure 2 – Upper-air charts for 980113, 0000 UTC at a) 300 and b) 500 mb.



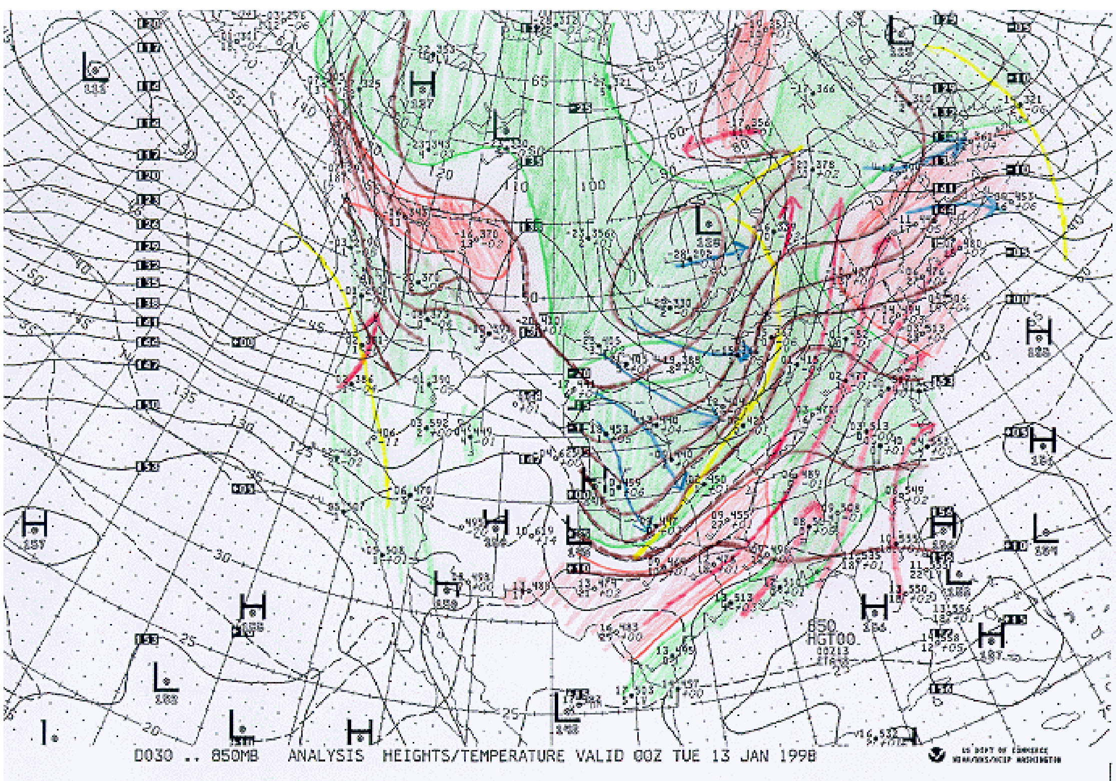


Figure 2 – Upper-air charts for 980113, 0000 UTC at c) 700 and d) 850 mb.

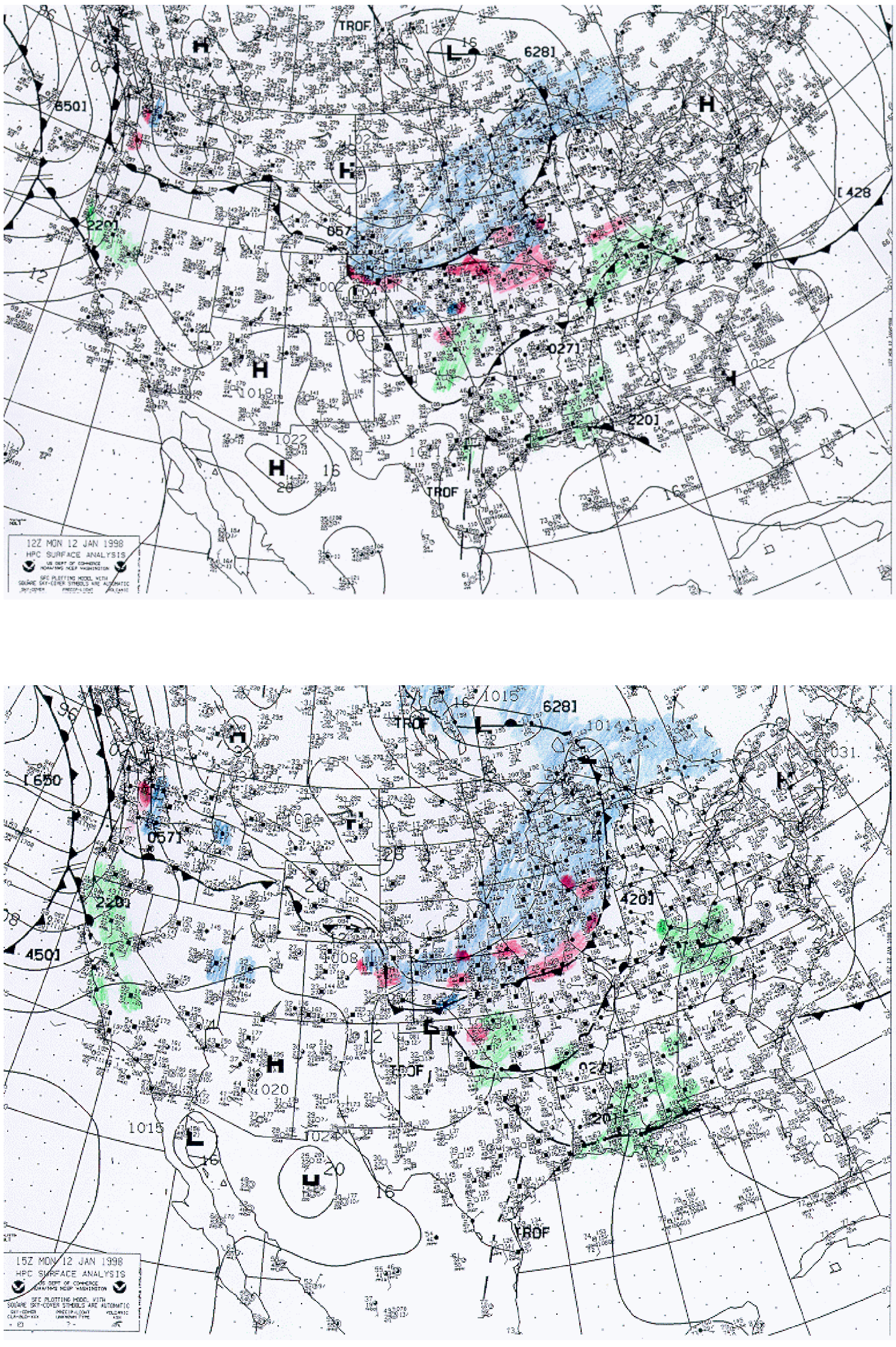
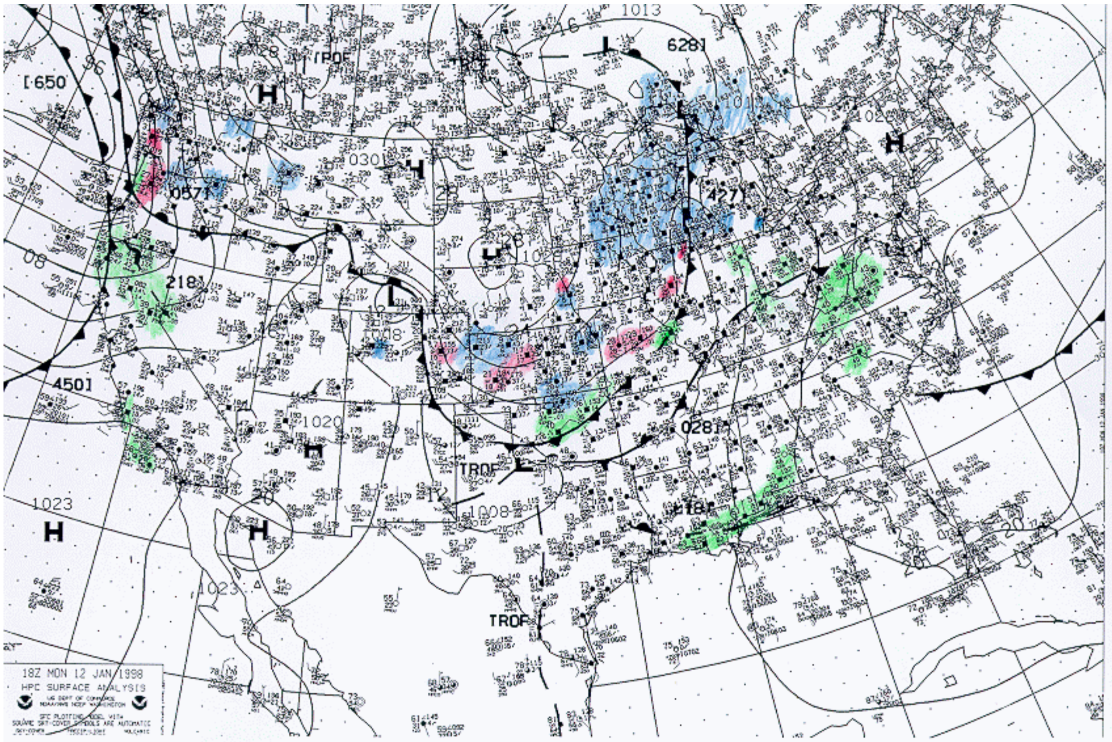


Figure 3 – Surface charts for 980112, a) 1200 and b) 1500 UTC.



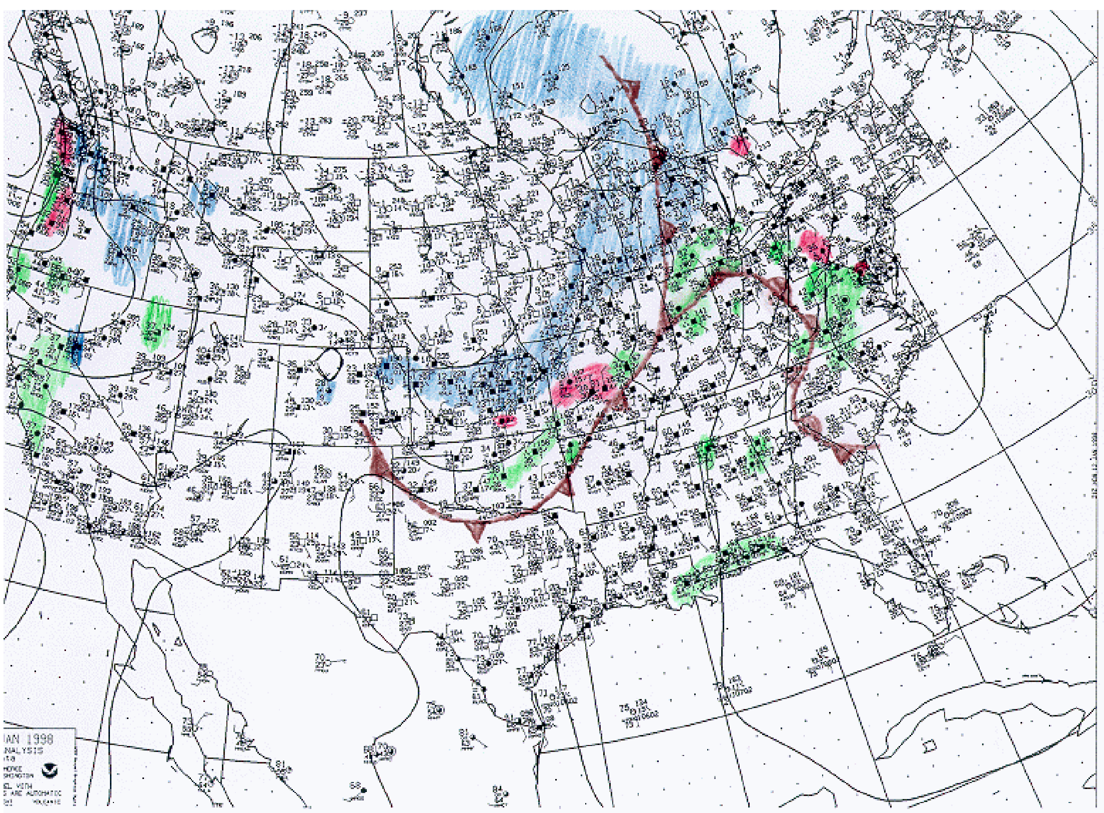


Figure 3 – Surface charts for 980112, c) 1800 and d) 2100 UTC.

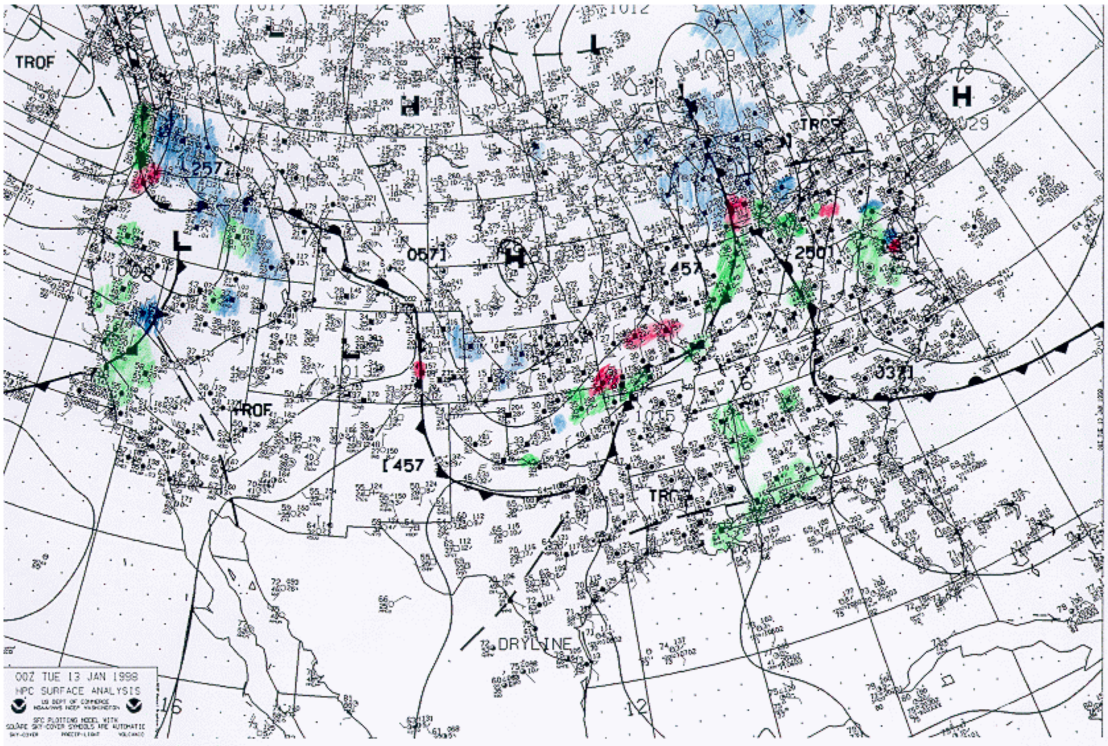
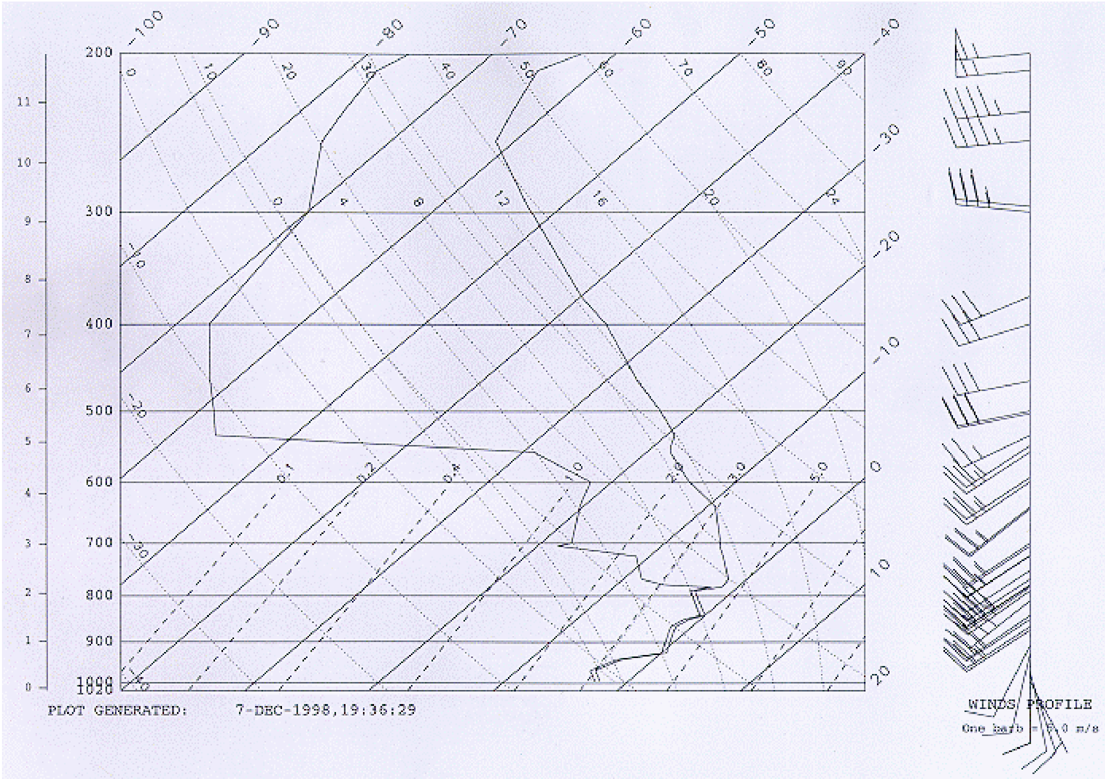


Figure 3 – Surface chart for e) 980113, 0000 UTC.



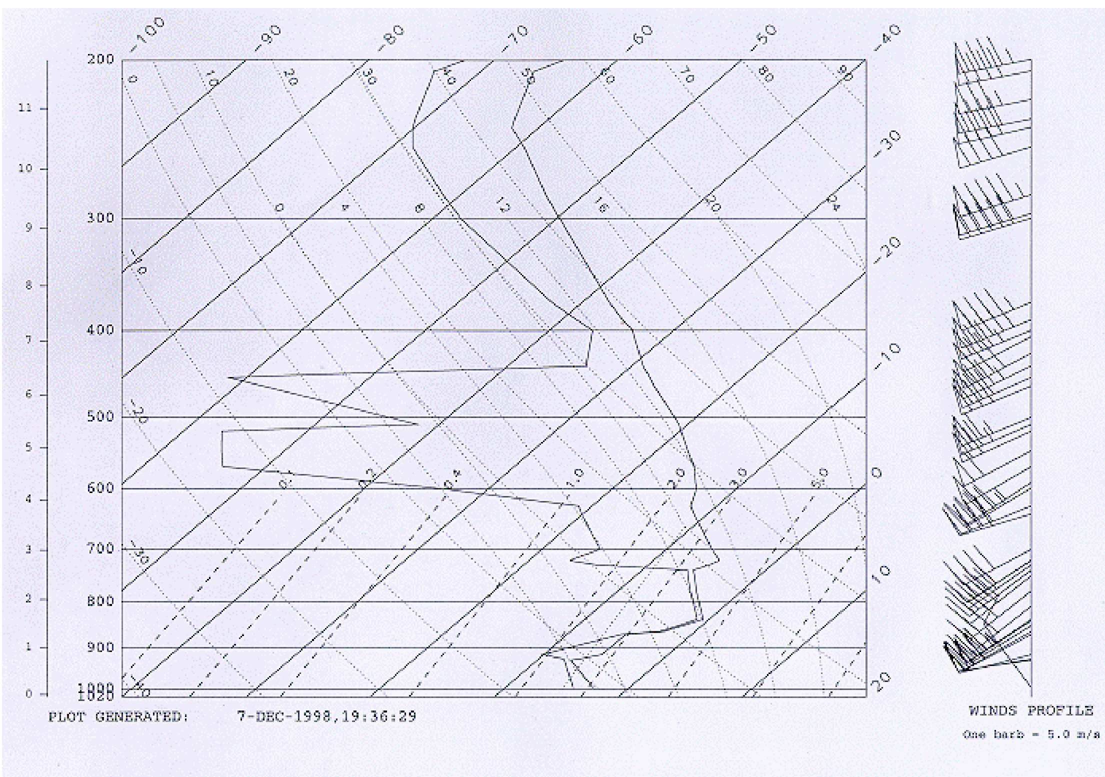
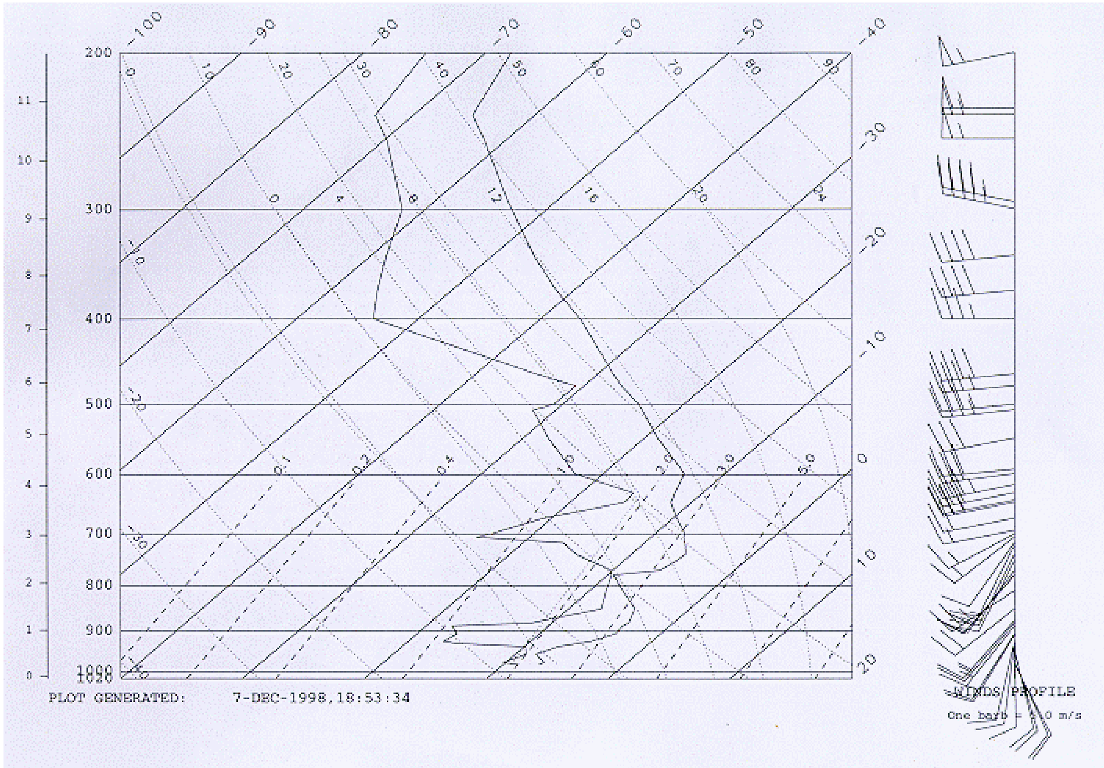


Figure 4 – Balloon-borne soundings from Lincoln IL for a) 980112, 1200 and b) 980113, 0000 UTC.



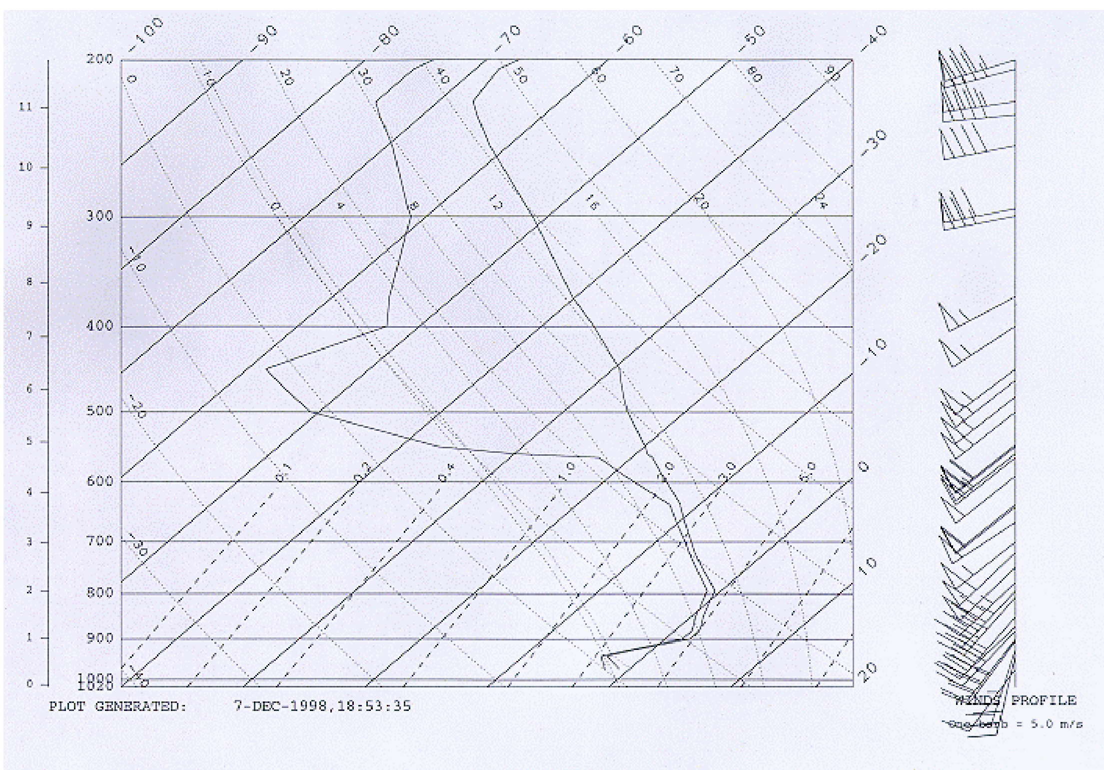
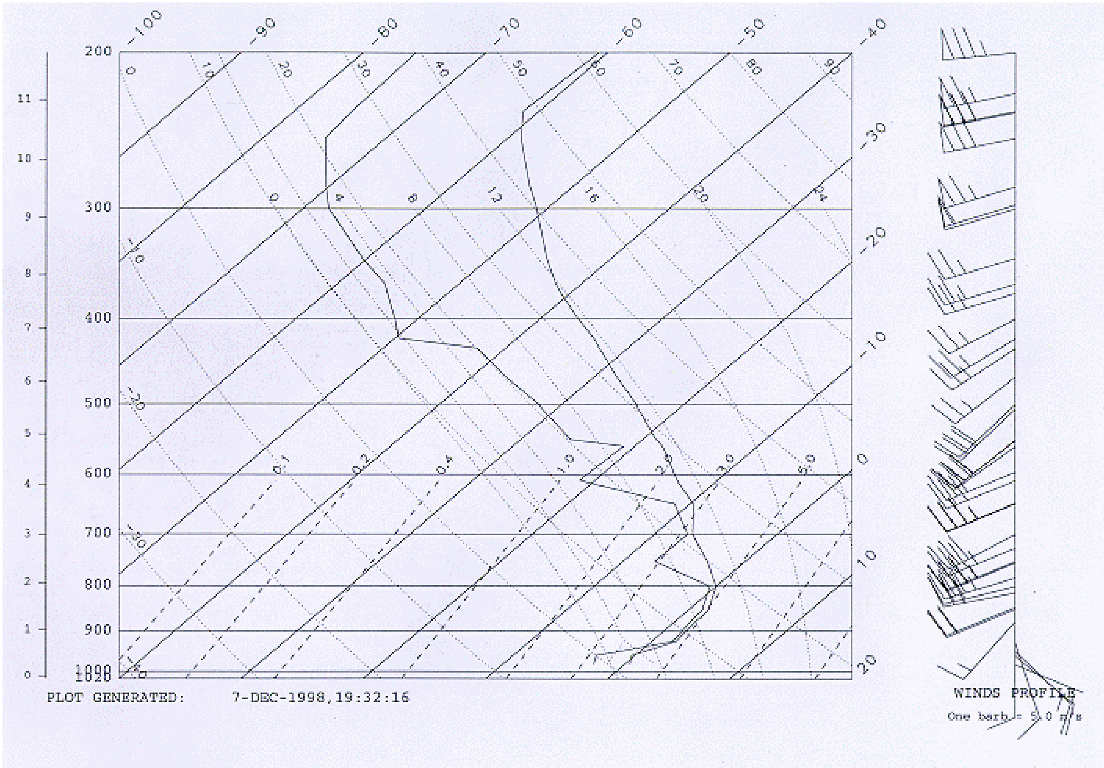


Figure 4 – Balloon-borne soundings from Detroit for c) 980112, 1200 and d) 980113, 0000 UTC.



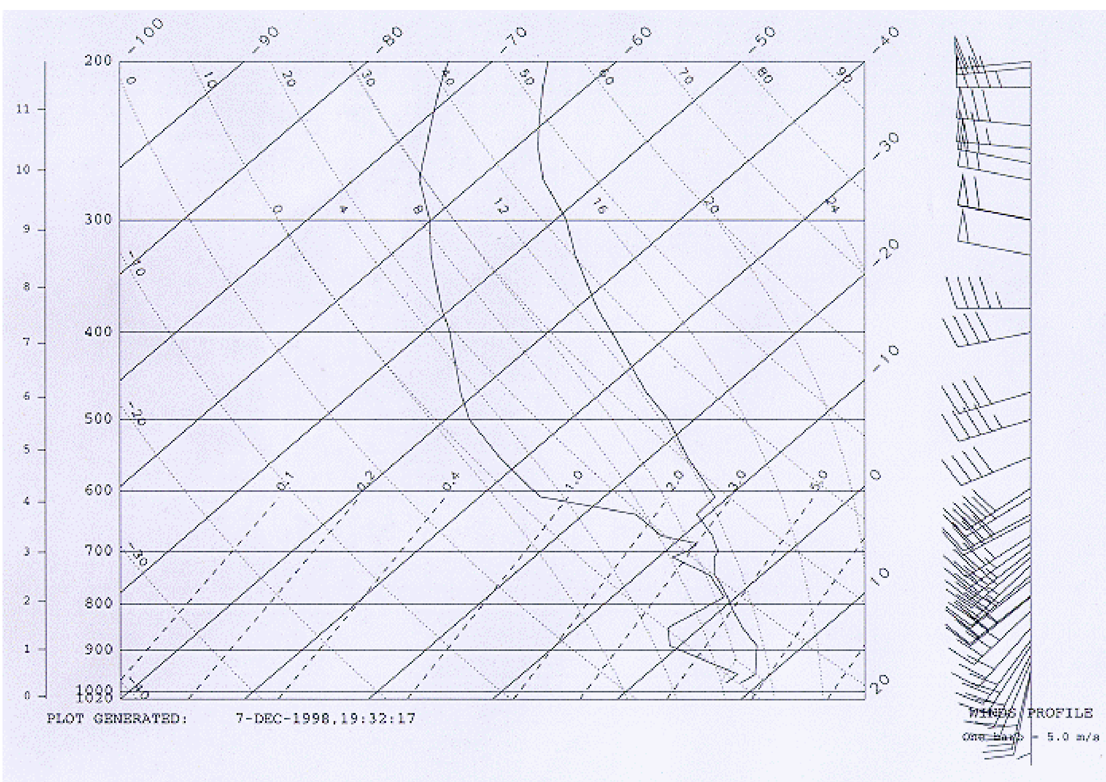


Figure 4 – Balloon-borne soundings from Wilmington for e) 980112, 1200 and f) 980113, 0000 UTC.

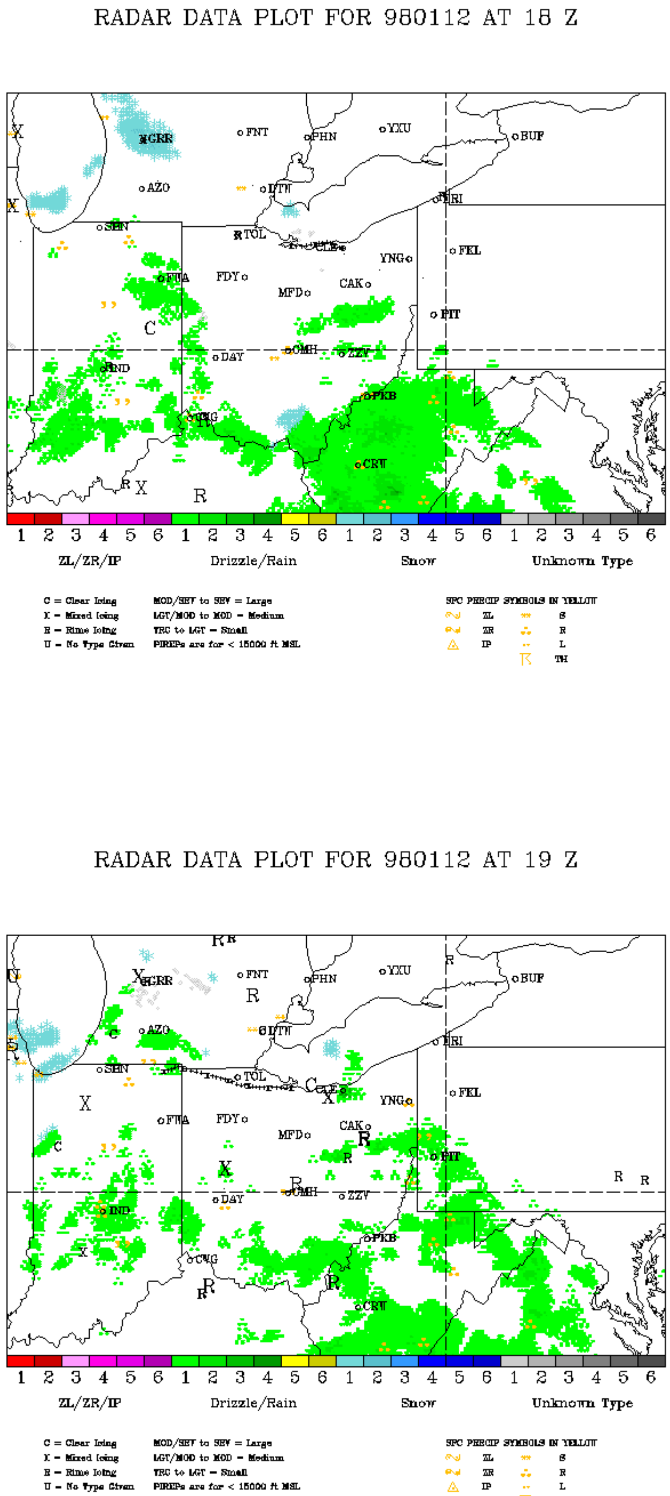
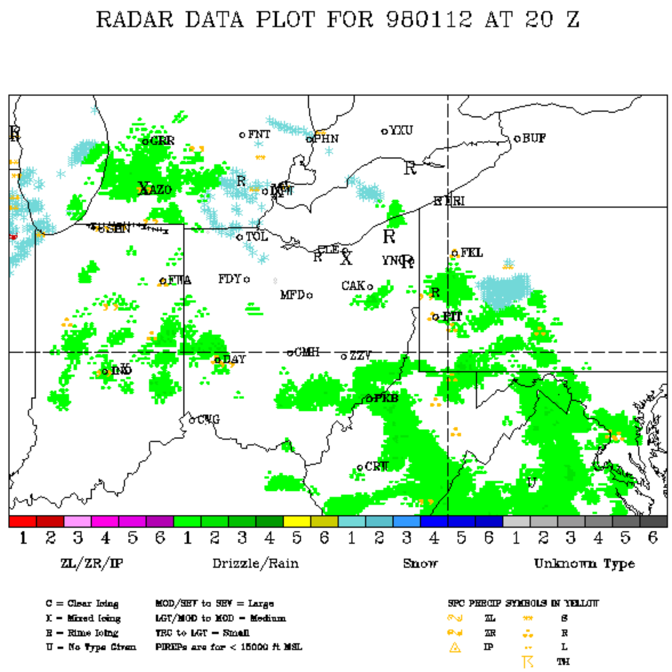


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980112, a) 1800 and b) 1900 UTC.



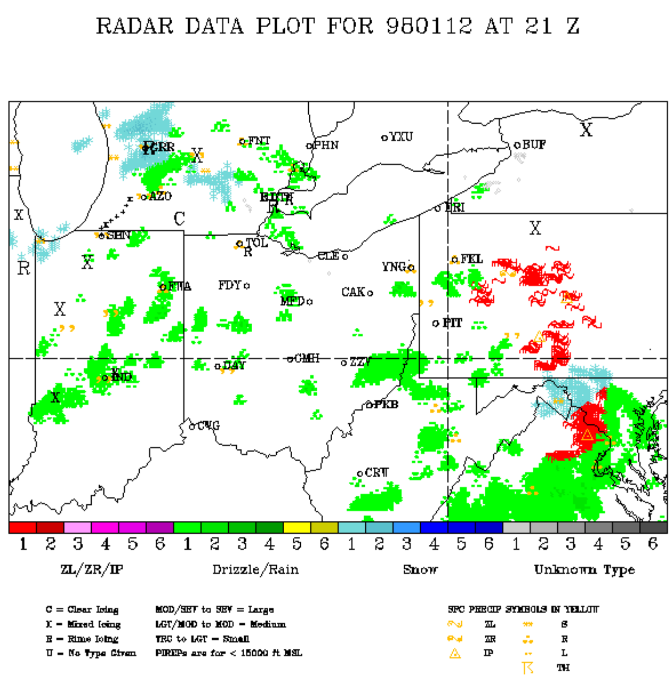
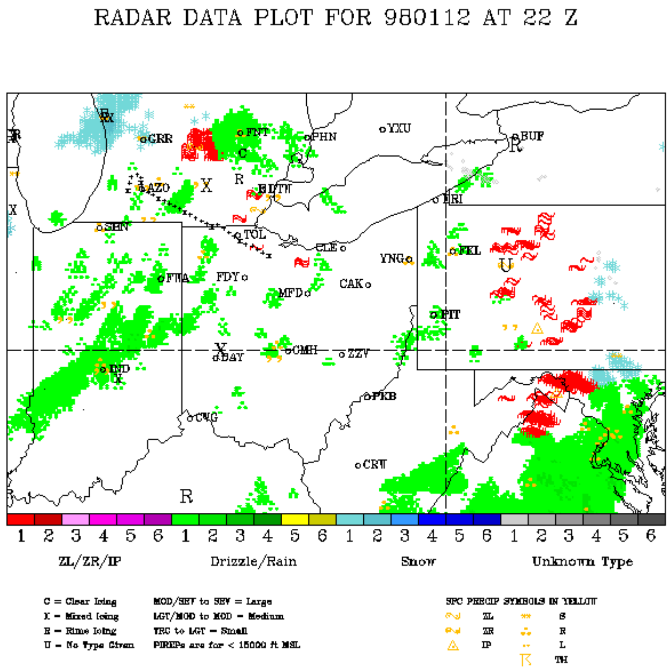


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980112, c) 2000 and d) 2100 UTC.



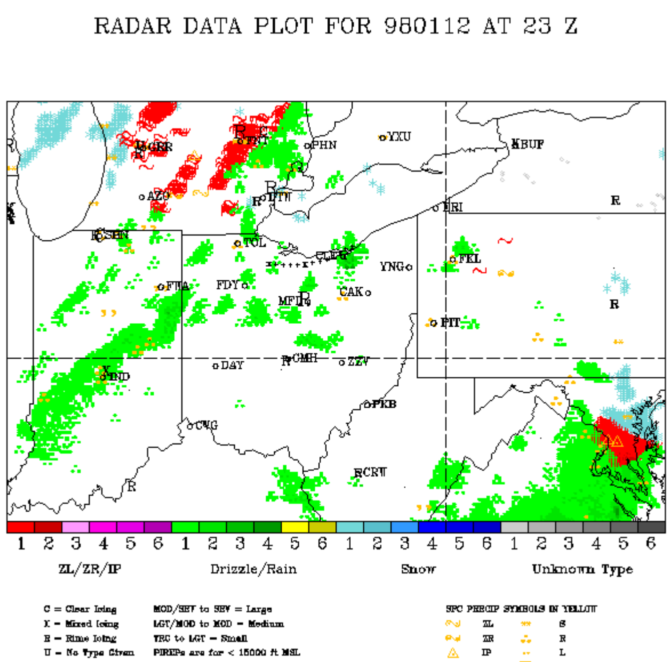
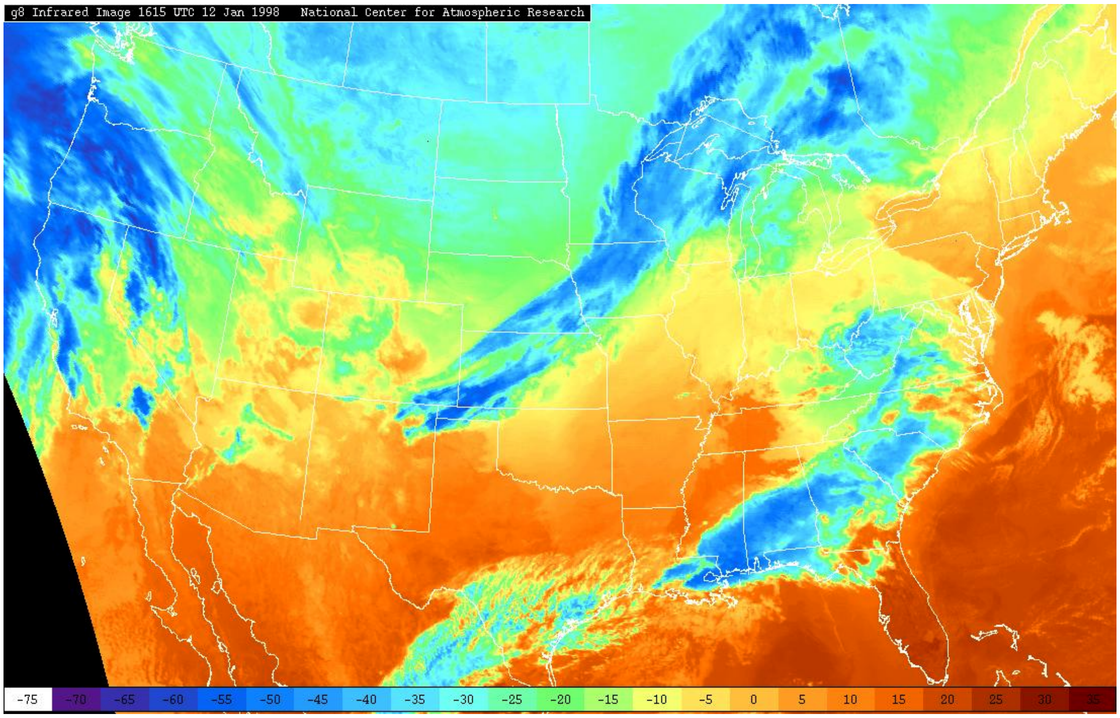


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980112, e) 2200 and f) 2300 UTC.



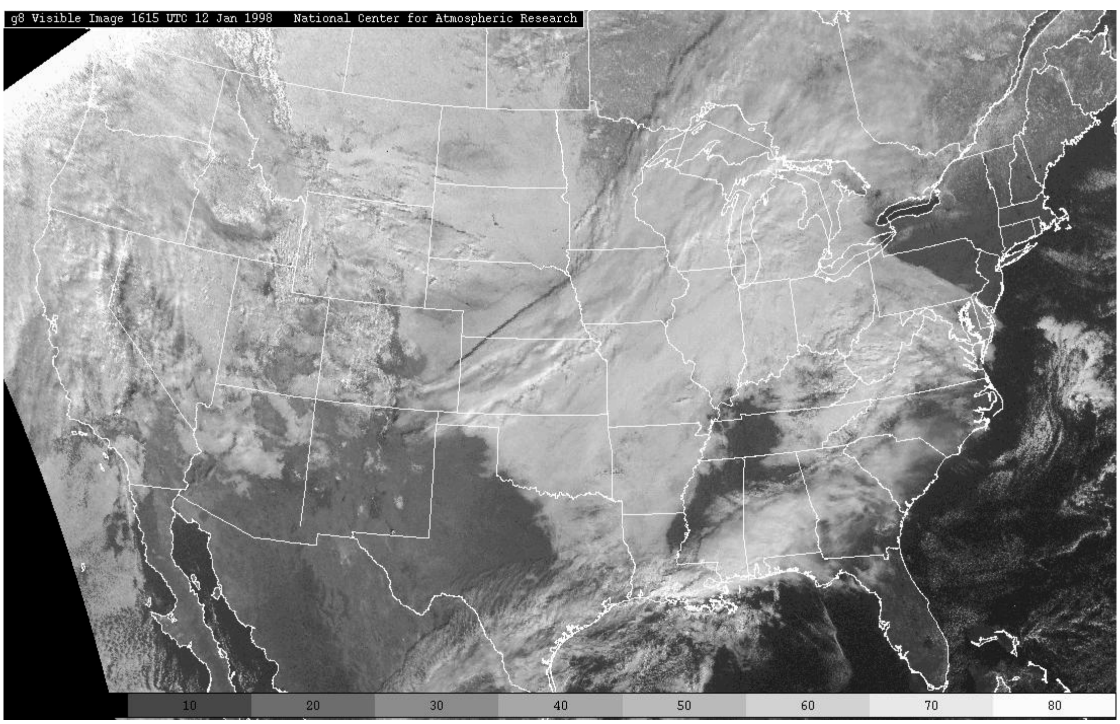
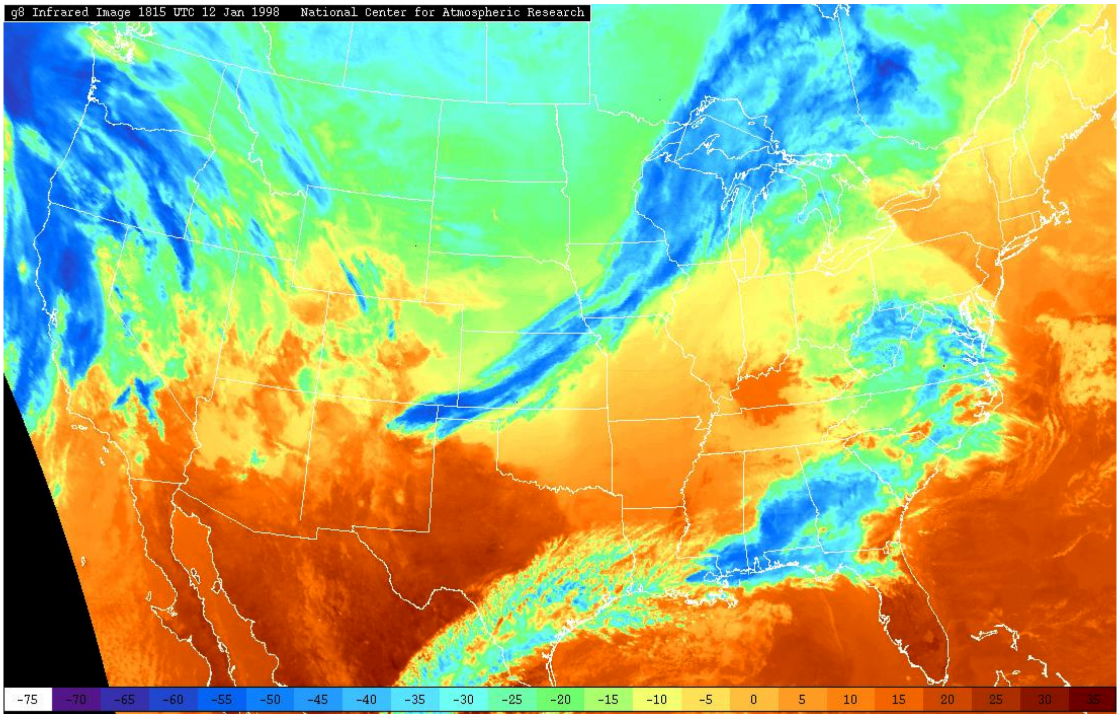


Figure 6 – GOES-8 a) infrared and b) visible satellite images for 980112, 1615 UTC.



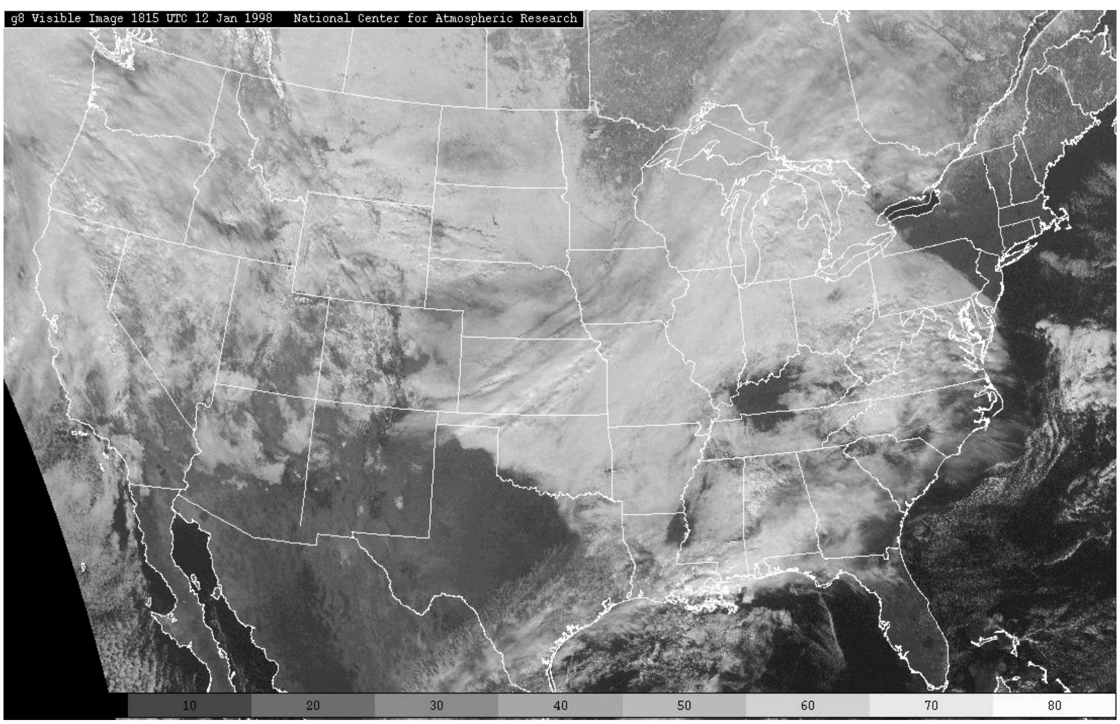
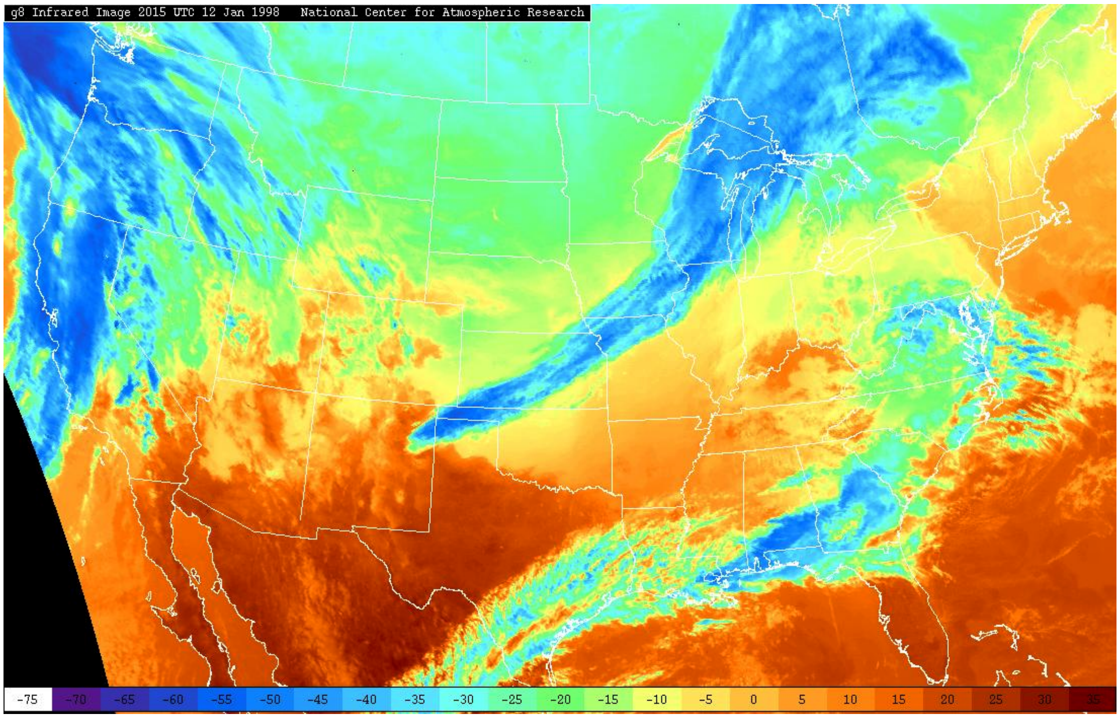


Figure 6 – GOES-8 c) infrared and d) visible satellite images for 980112, 1815 UTC.



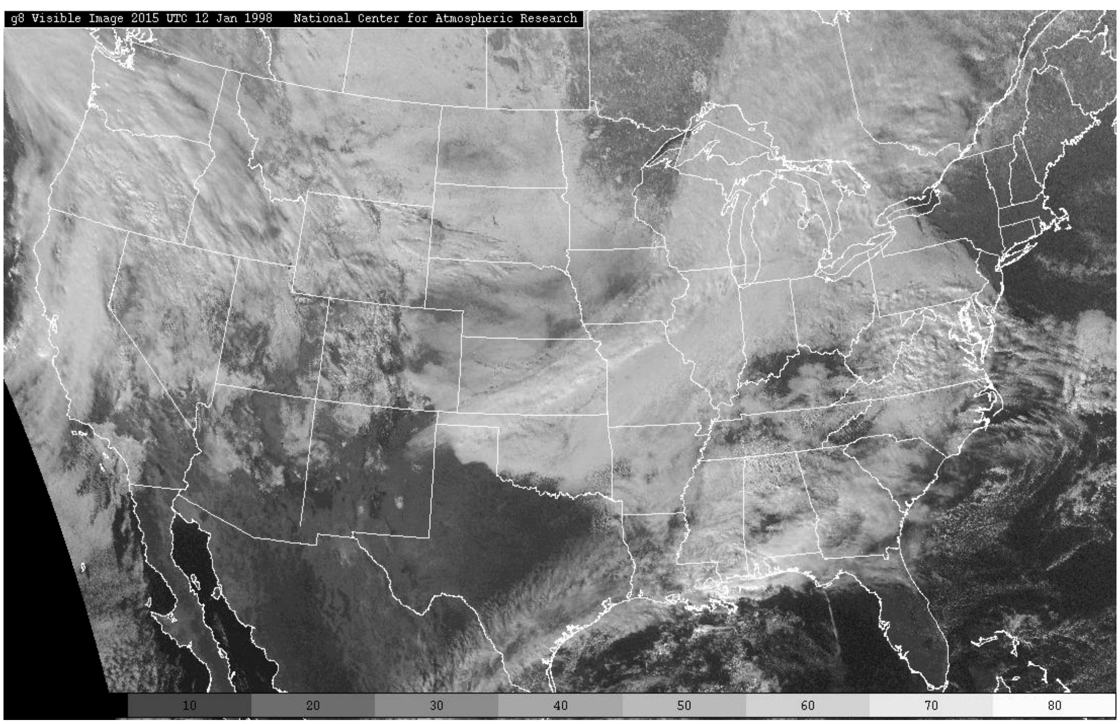
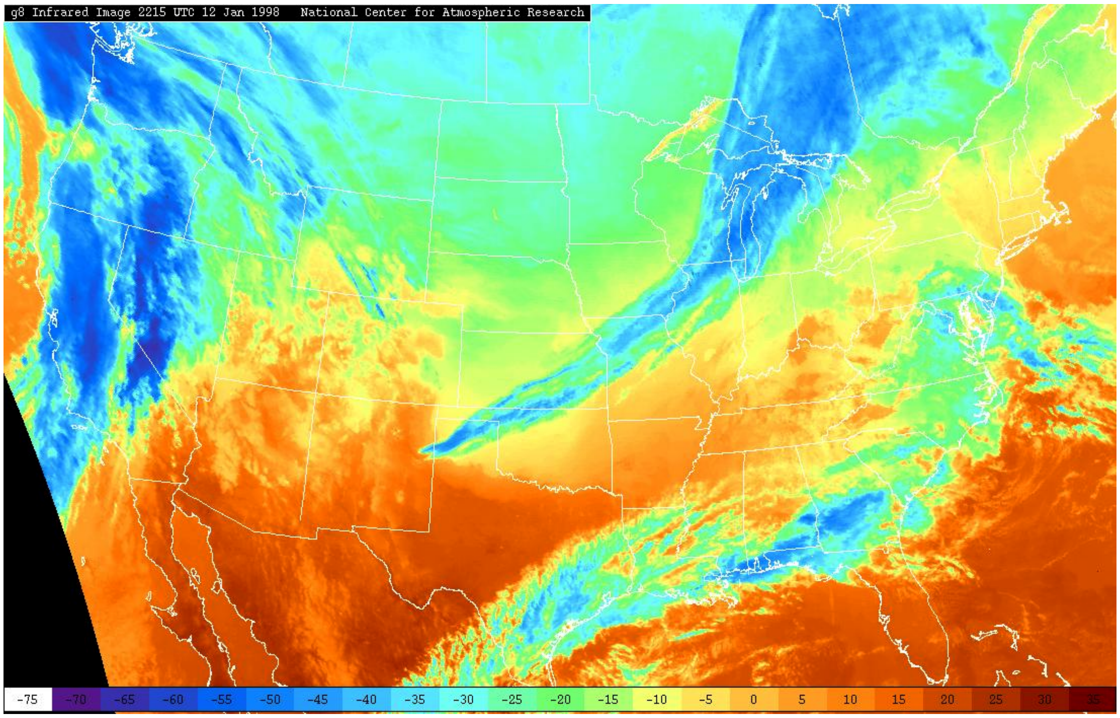


Figure 6 – GOES-8 e) infrared and f) visible satellite images for 980112, 2015 UTC.



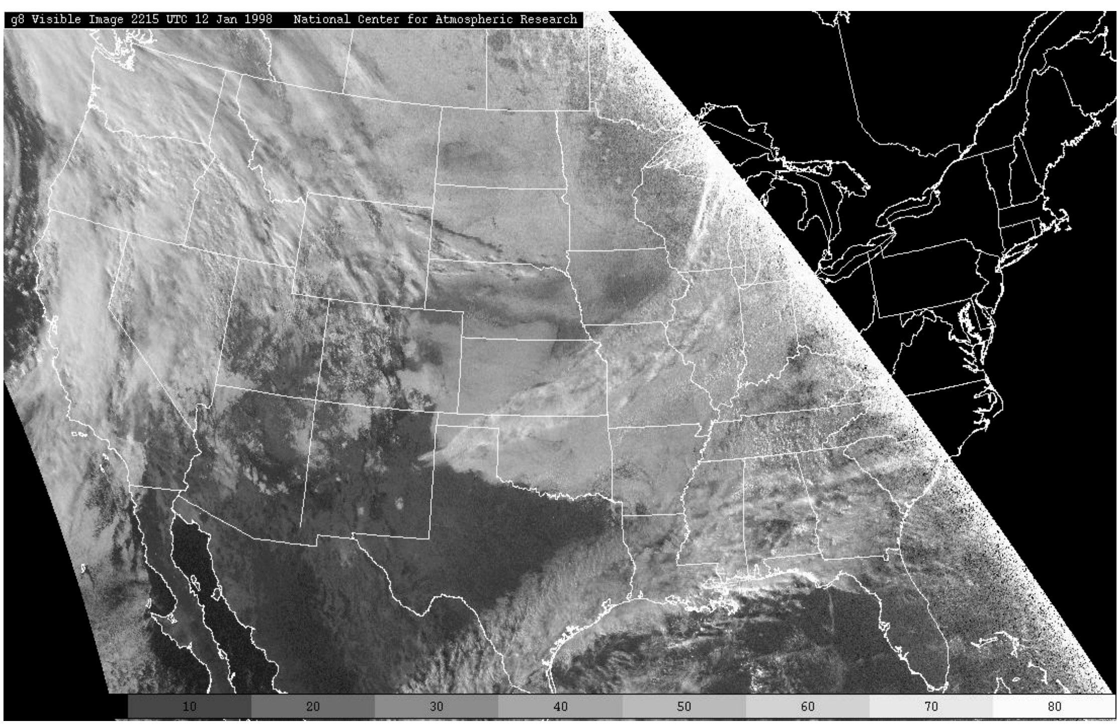
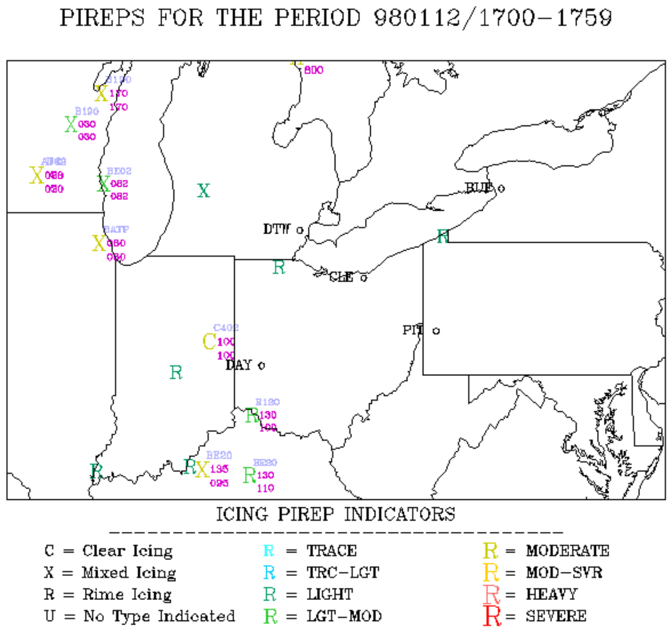


Figure 6 – GOES-8 g) infrared and h) visible satellite images for 980112, 2215 UTC.



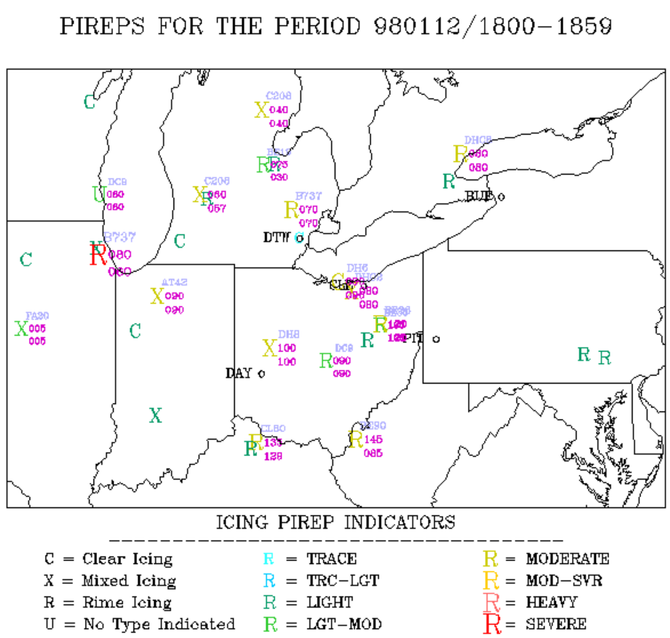
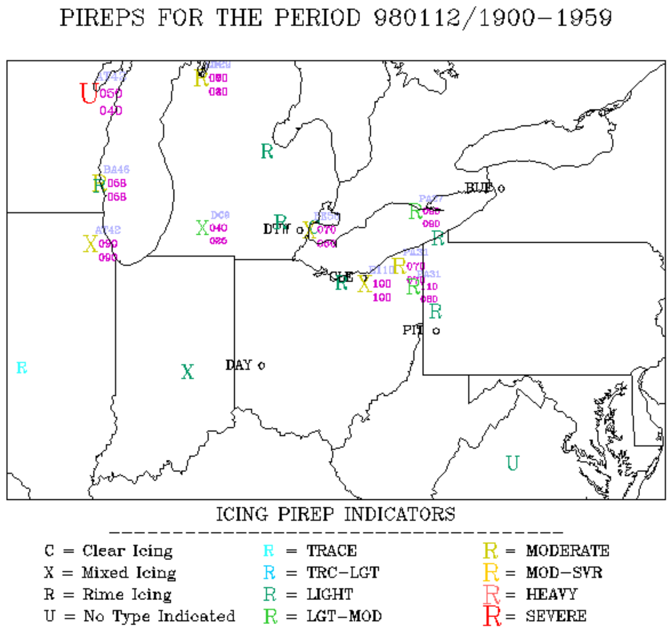


Figure 7 – Pilot reports of icing for 980112, a) 1700-1759 and b) 1800-1859 UTC.



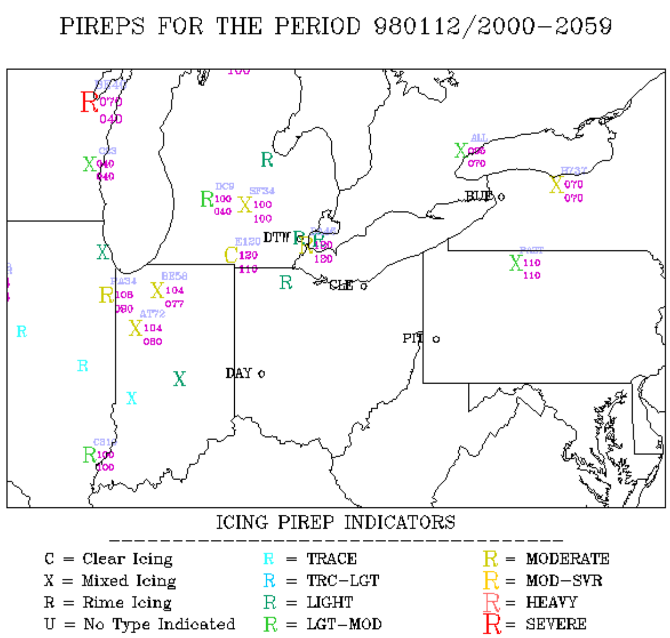
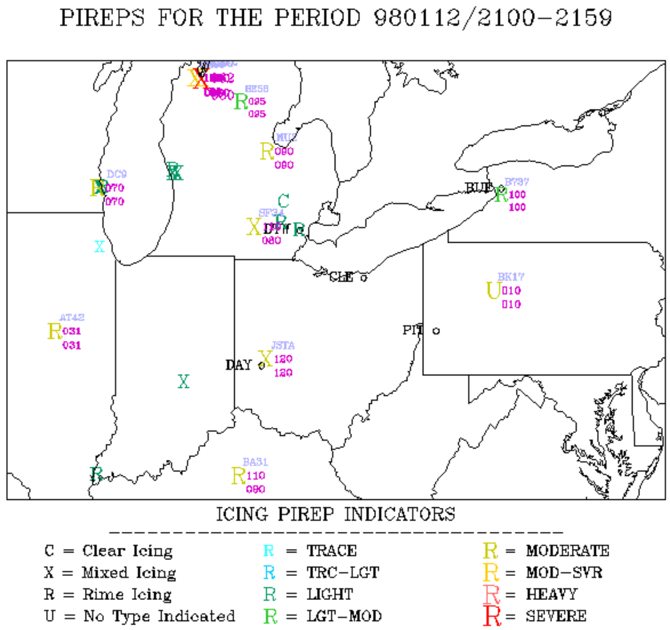


Figure 7 – Pilot reports of icing for 980112, c) 1900-1959 and d) 2000-2059 UTC.



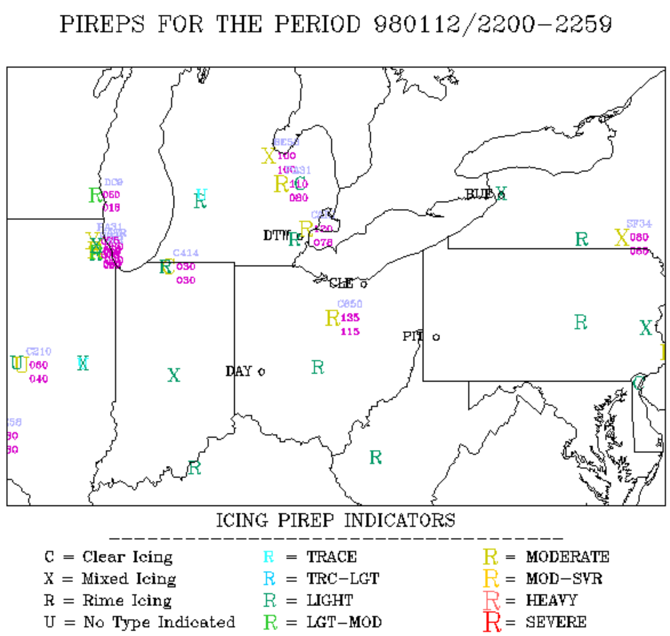


Figure 7 – Pilot reports of icing for 980112, e) 2100-2159 and f) 2200-2259 UTC.

January 22, 1998

Flight #1—Over Cleveland, OH, and Erie, PA, from 1300 to 1456 UTC.

Flight #2—Over Cleveland, OH, from 1557 to 1653 UTC.

Brief overview

On this day, two flights were made into mostly mixed conditions along the south shore of Lake Erie. During the first flight, a mixture of some freezing drizzle (ZL) and ice crystals was observed during both initial climb out from and final descent into Cleveland. Otherwise, the entire first flight was characterized by mixed conditions within clouds and snow between decks. The clouds varied in altitude, depth, and LWC along the shoreline. Two cloud decks were initially observed over Cleveland, one from 2000’ to 5100’ with a CTT of –3C, and another from 9900’ to 11,400’ with a CTT of –15C. Some in-focus ZL was found between cloud layers at 6000’ to 6500’. Peak LWCs were about 0.25 in several of the cloud layers sampled on this day, including the highest cloud layer. The highest cloud tops were somewhat warmer (-12C) during the second flight, but only snow and small droplet, mixed phase conditions were found. No ZL was observed during the second flight.

Relevant weather features

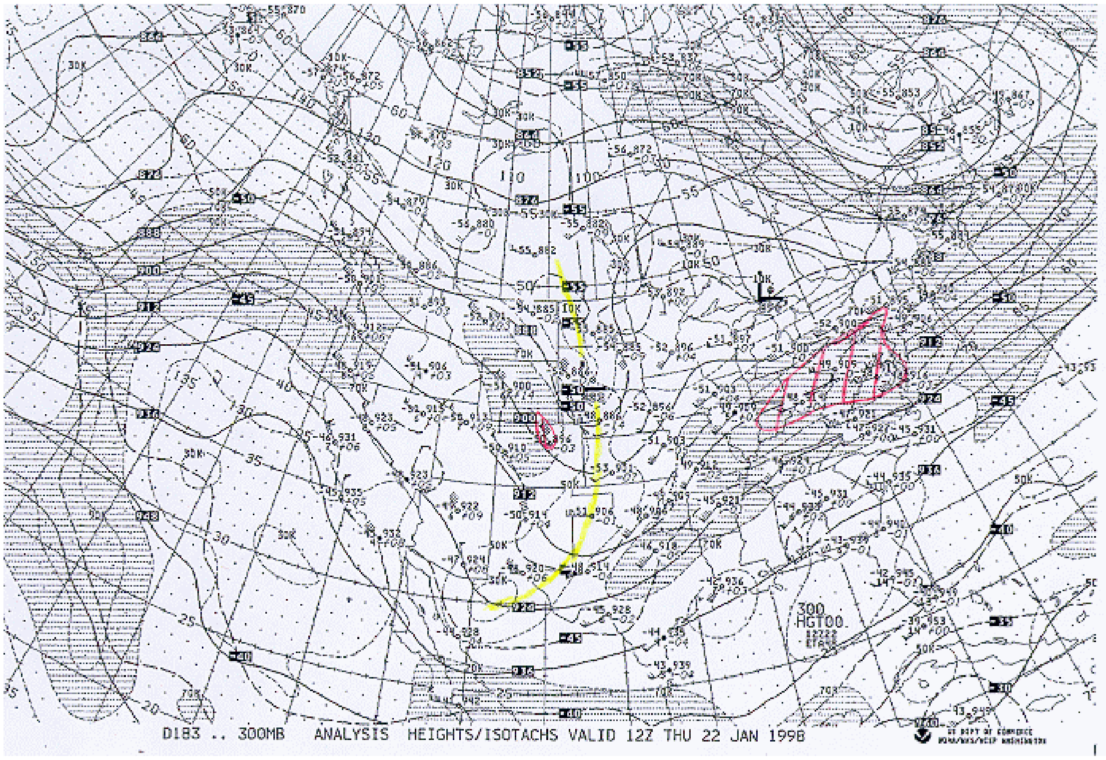
At 1200 UTC, a 300 mb trough was in place across the western Great Plains (Fig. 1). A small jet core of 90+ knots was located over Ohio, but dry conditions at 500mb appear to have precluded any effects from jet dynamics on the clouds sampled. Much weaker winds were evident to the north, over Lake Huron. At 500 mb, dry conditions and warm advection existed across the forecast area, and a trough was in place over the western High Plains. At 700 mb, a trough was more evident across the center of the country. Some cold advection was occurring behind it, while warm advection was prevalent across most of the Midwest. Saturated conditions covered most of the eastern two-thirds of the country, and temperatures within the moist air over Ohio were between -8C and -11C at this level. A trough axis was found across the northern borders of Indiana and Ohio. This trough was more obvious at 850 mb, and was connected to a weak low along the Iowa/Missouri border. Warm advection was quite strong near the trough axis, across Ohio, Pennsylvania and western New York. Again, saturated conditions covered most of the eastern two-thirds of the country. The exception was an area of very dry conditions over New England, where cold advection was found in association with a weak trough.

The 1200 and 1500 UTC surface charts (Fig. 2) had a relatively strong, 1040 mb high along the Ontario/Quebec border that was nosing into New England and the mid-Atlantic states. A weak, 1018 mb low was centered over southern Indiana, from which a trough extended across central Ohio and a cold front ran southwest to Louisiana. A swath of snow covered areas from western Pennsylvania to the Dakotas, including across extreme northern Ohio and Indiana. At times, small pockets of freezing precipitation were observed in northern Indiana, northern Illinois, and Iowa.

Soundings taken by the NCAR CLASS system at 1127 and 1523 UTC (Fig. 3) revealed strong stability and warm advection (veering winds with height) below about 900 mb, where the trough axis is likely to have crossed over Cleveland. A shallow dry layer was evident between the top of the lower cloud deck and a higher cloud deck (with CTT near -14C) from 810 to 700 mb. By 1523 UTC, cloud tops were lower, warmed to -12C, and the intermediate dry layer appeared to moisten. Other soundings taken around the area at 1200 UTC showed a single cloud layer with varying depths and CTTs (-8C at Wilmington and Lincoln IL (near Chicago), -16C at Detroit, and -20C at Buffalo). The Detroit and Buffalo soundings were both taken within much deeper, colder clouds to the north of the 850 mb trough, where snow was observed at the surface. The Wilmington and Lincoln soundings were taken to the south of and along the 850 mb trough, respectively.

Infrared satellite imagery from 1215 UTC (Fig. 4) indicated the existence of relatively cold cloud tops near Buffalo and Detroit, and patches of warmer cloud tops near Lincoln and Wilmington. CTTs were between –10C and -15C over southern Lake Erie, but pockets of colder cloud tops were observed just to the south, and more widespread, cold cloud tops moved northward into Ohio by 1615 UTC. During the same period, an area of warm (-10C) CTTs expanded across southern Michigan and had nearly reached Cleveland by 1815 UTC.

Regional radar imagery for 1300 and 1400 UTC (Fig. 5) show the swath of snow to the north and northeast of Cleveland, and some patchy ZL and possibly freezing rain over northern Indiana. The aircraft flew within and to the west of the intermittent, patchy swath of snow over extreme northeastern Ohio. Snow that was falling in southern Michigan dissipated with time, as warmer cloud tops moved into that area. Moderate rime and mixed icing PIREPs (Fig. 6) were made across the region at altitudes between 4000 and 14000'. PIREPs were especially common over Detroit early on, and over Chicago during the entire period. A couple of severe PIREPs were made over Chicago.



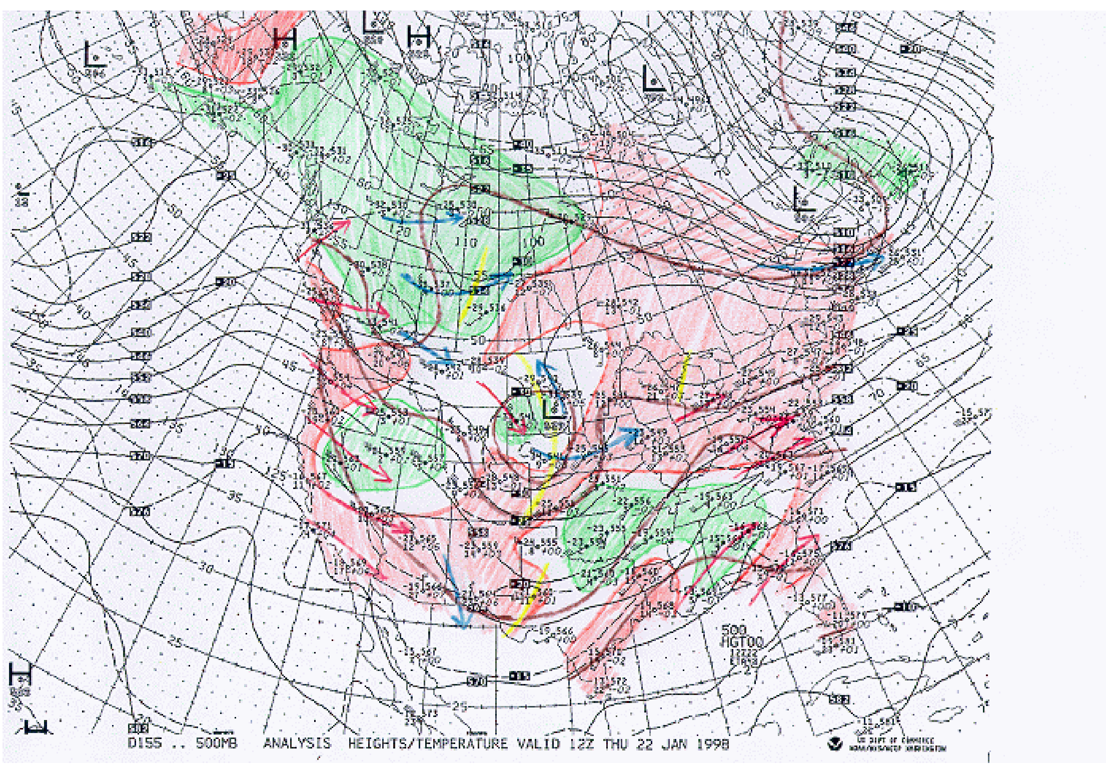
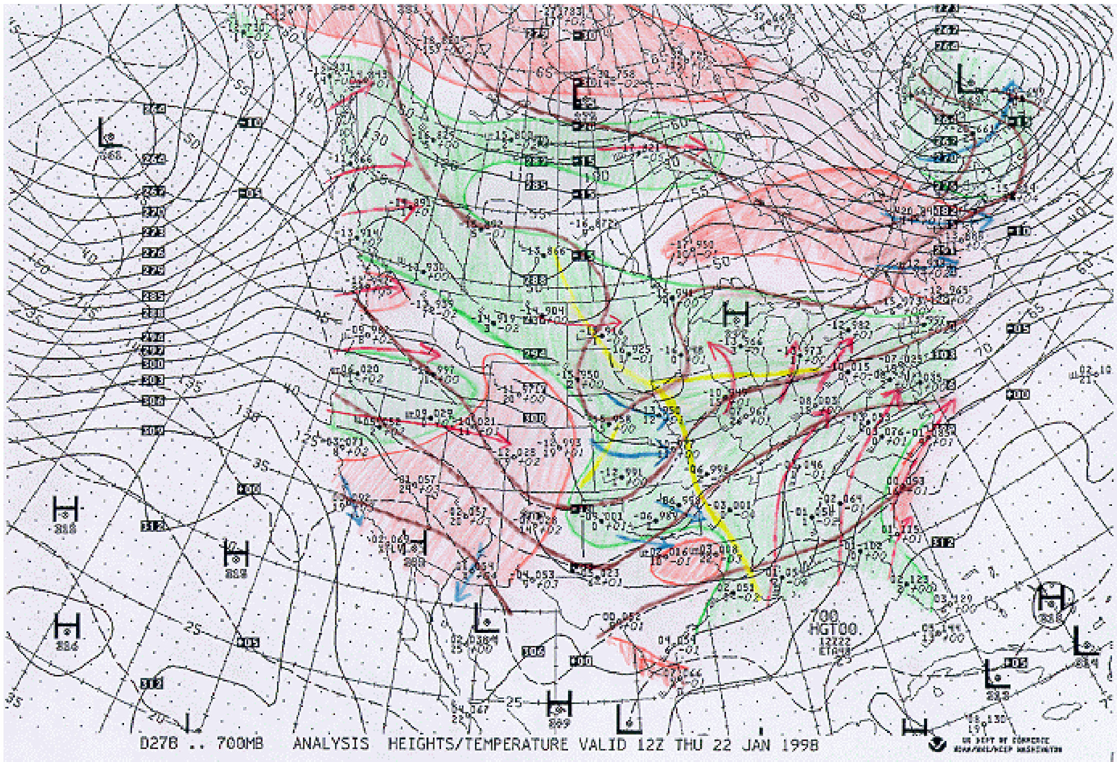


Figure 1 – Upper-air charts for 980122, 1200 UTC at a) 300 and b) 500 mb.



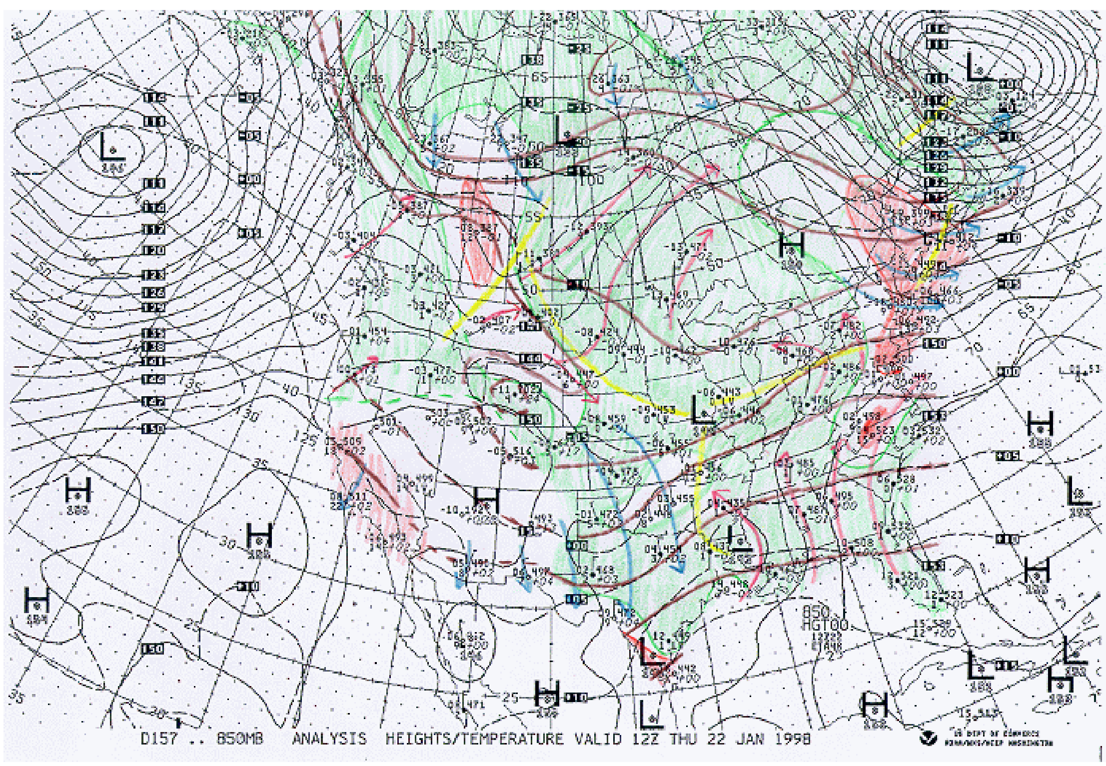
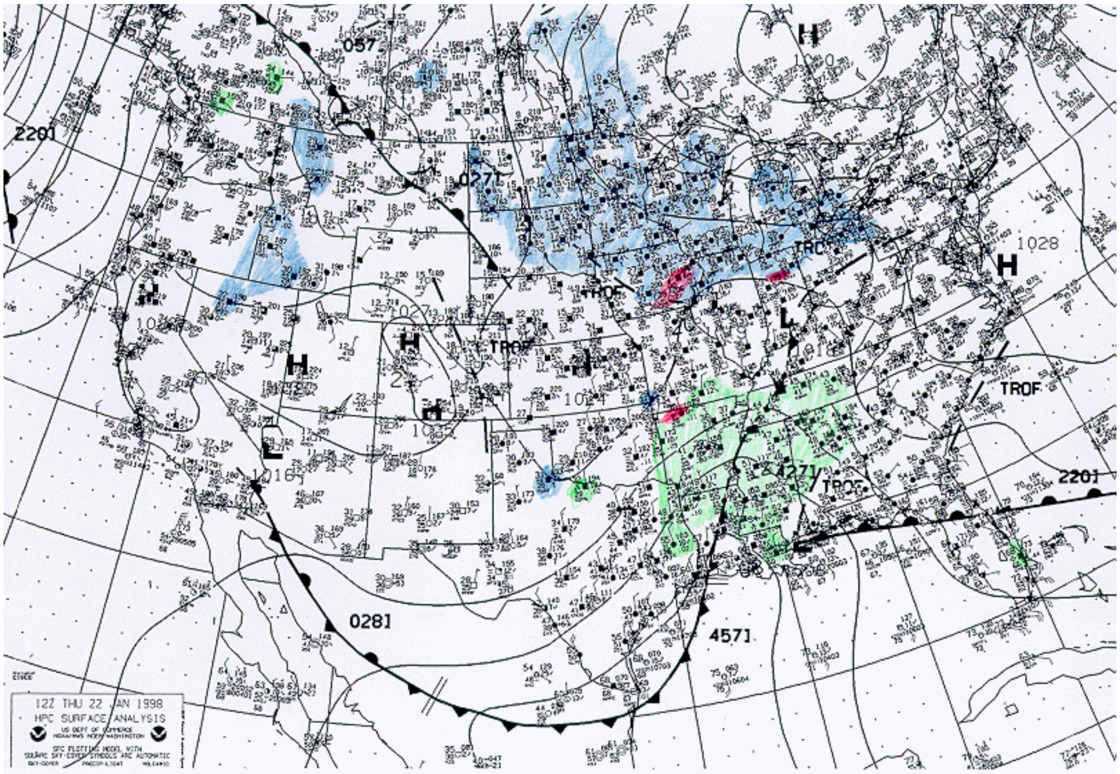


Figure 1 – Upper-air charts for 980122, 1200 UTC at c) 700 and d) 850 mb.



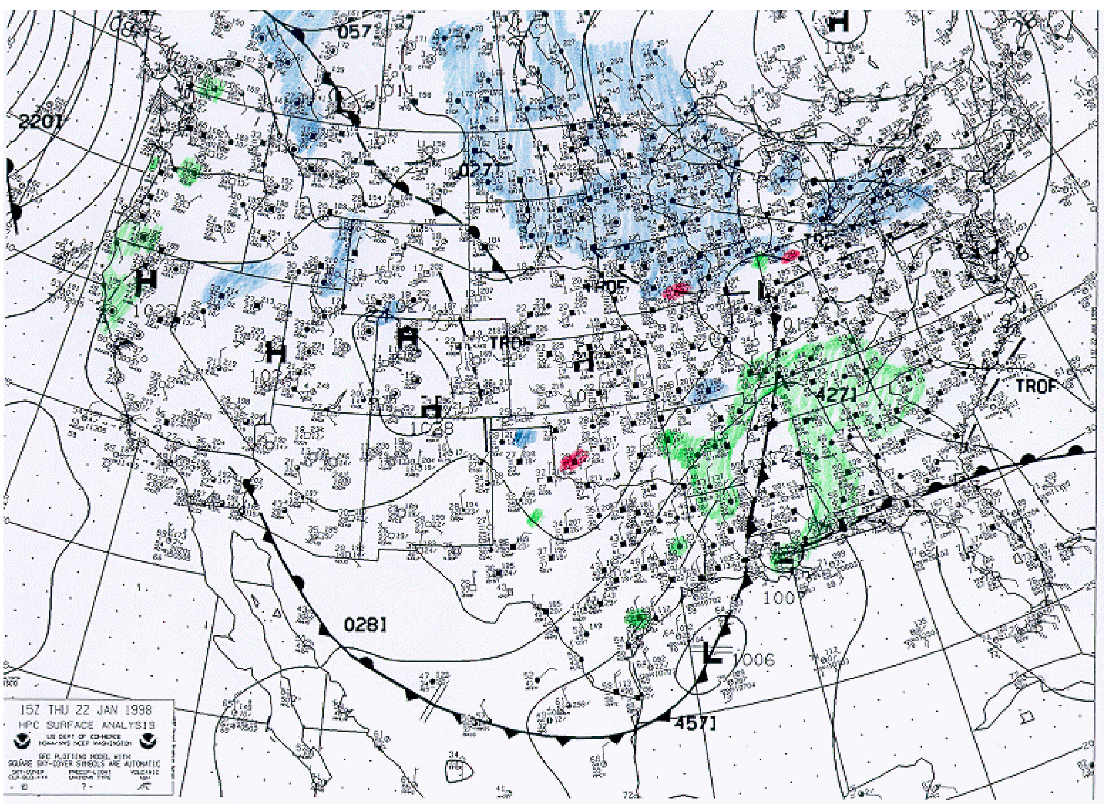
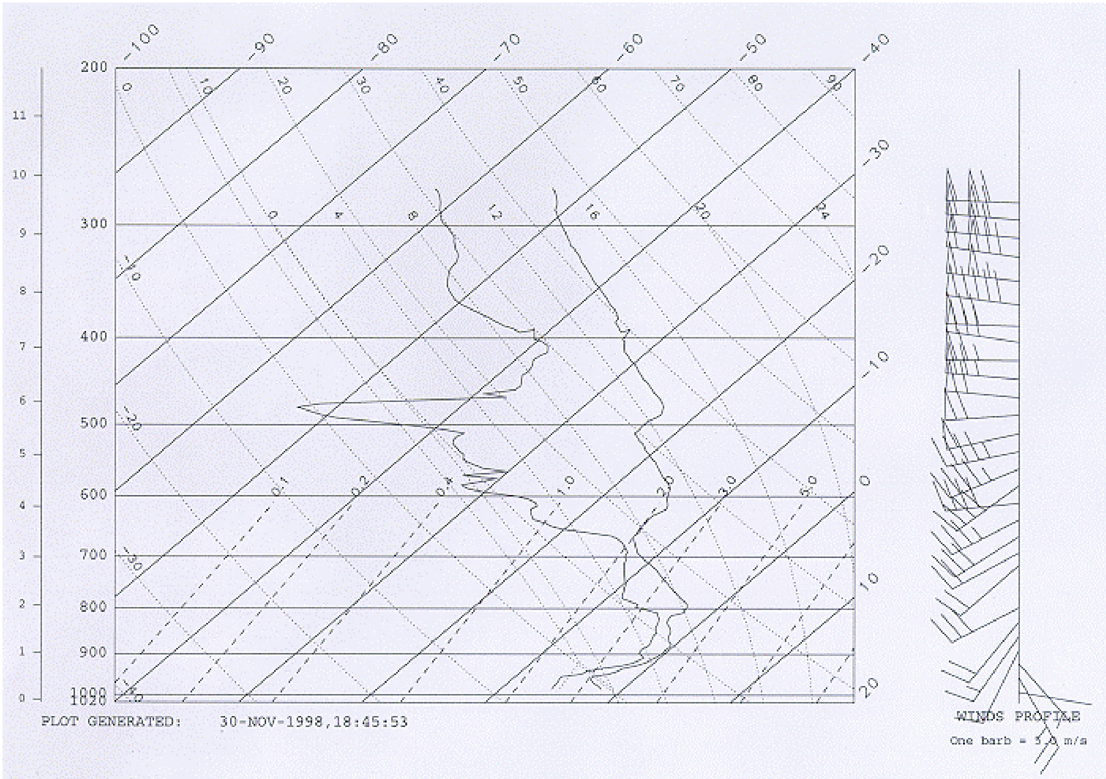


Figure 2 – Surface charts for 980122, a) 1200 and b) 1500 UTC.



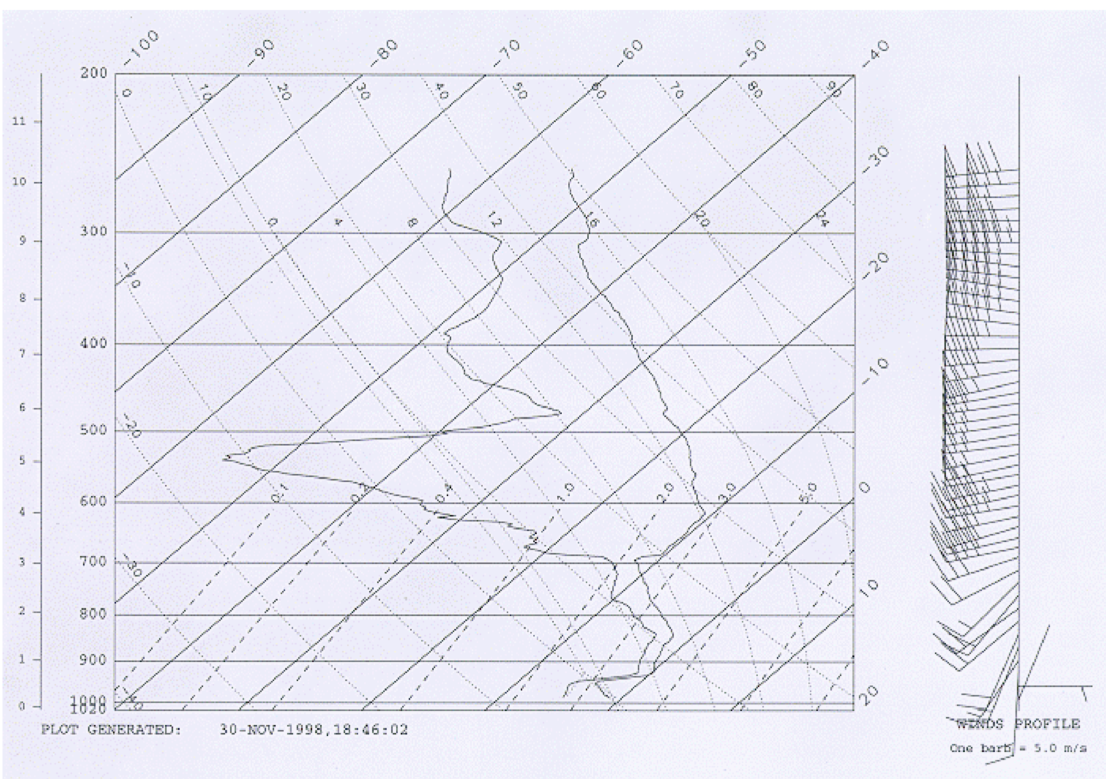


Figure 3 – Balloon-borne NCAR CLASS soundings from Cleveland OH for 980122, a) 1127 and b) 1523 UTC.

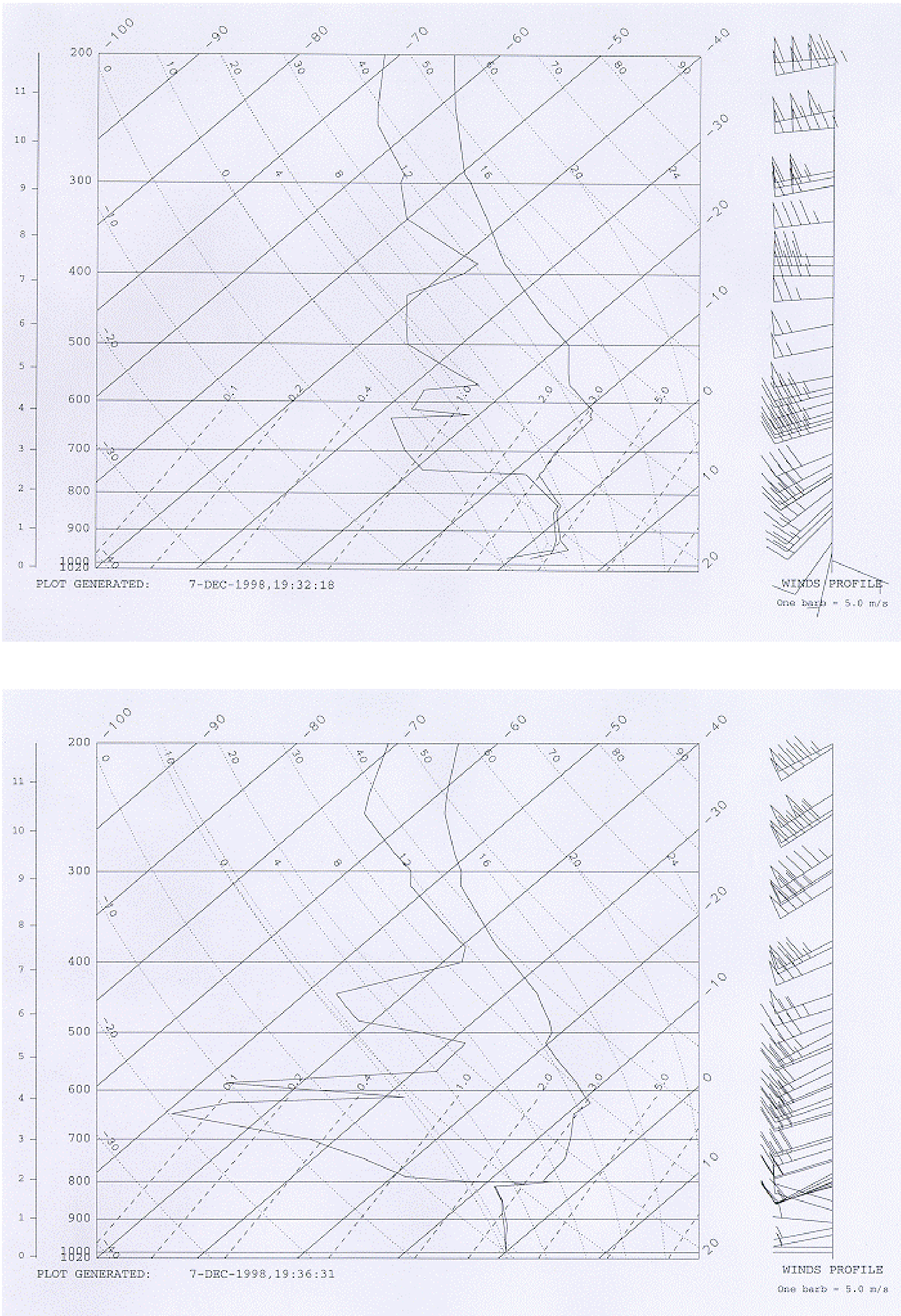
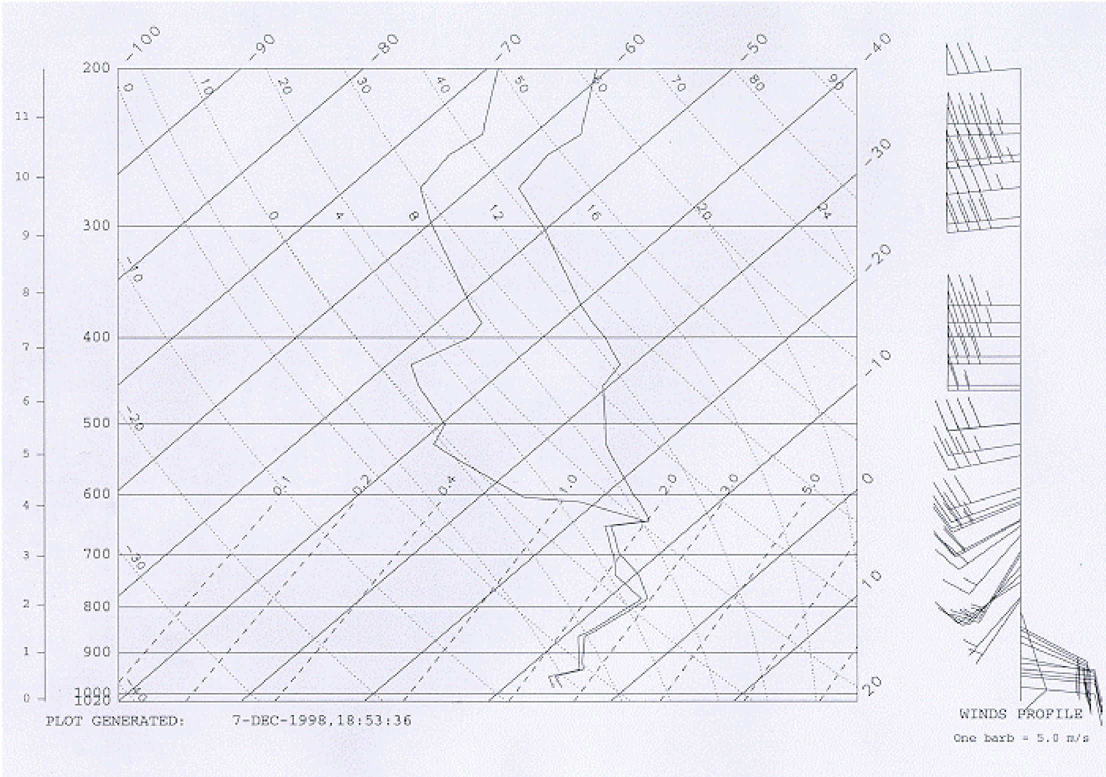


Figure 3 – Balloon-borne soundings from c) Wilmington and d) Lincoln IL for 980122, 1200 UTC.



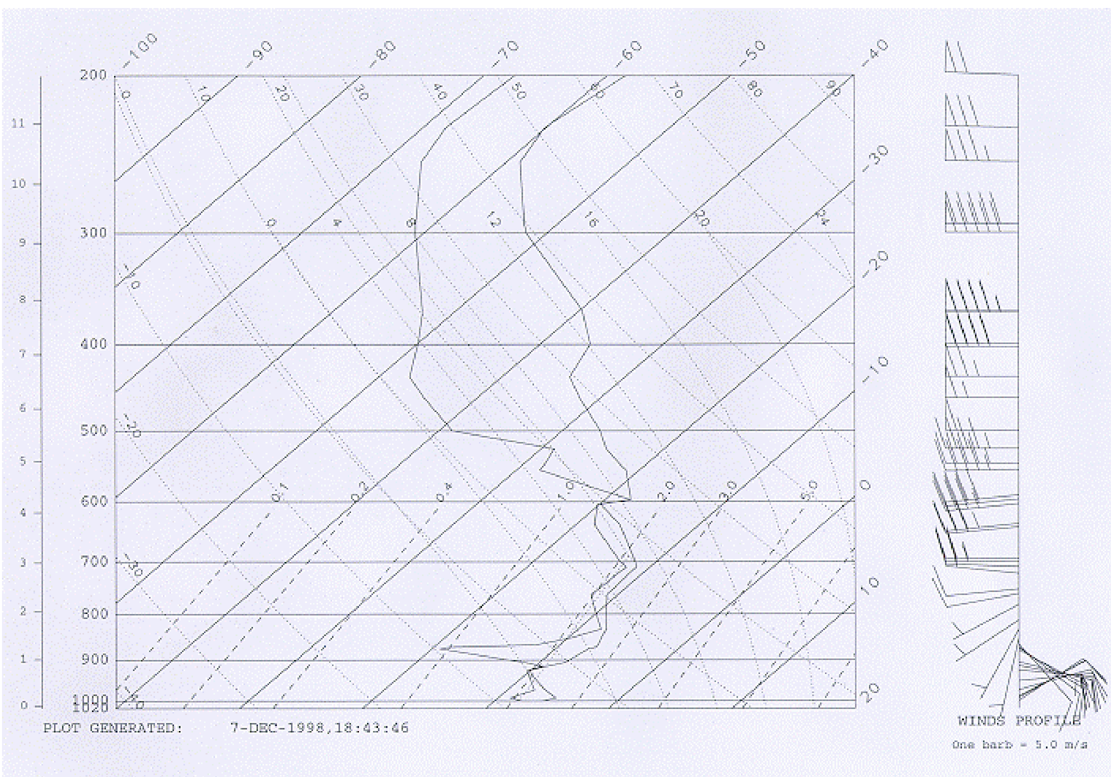


Figure 3 – Balloon-borne soundings from e) Detroit and f) Buffalo for 980122, 1200 UTC.

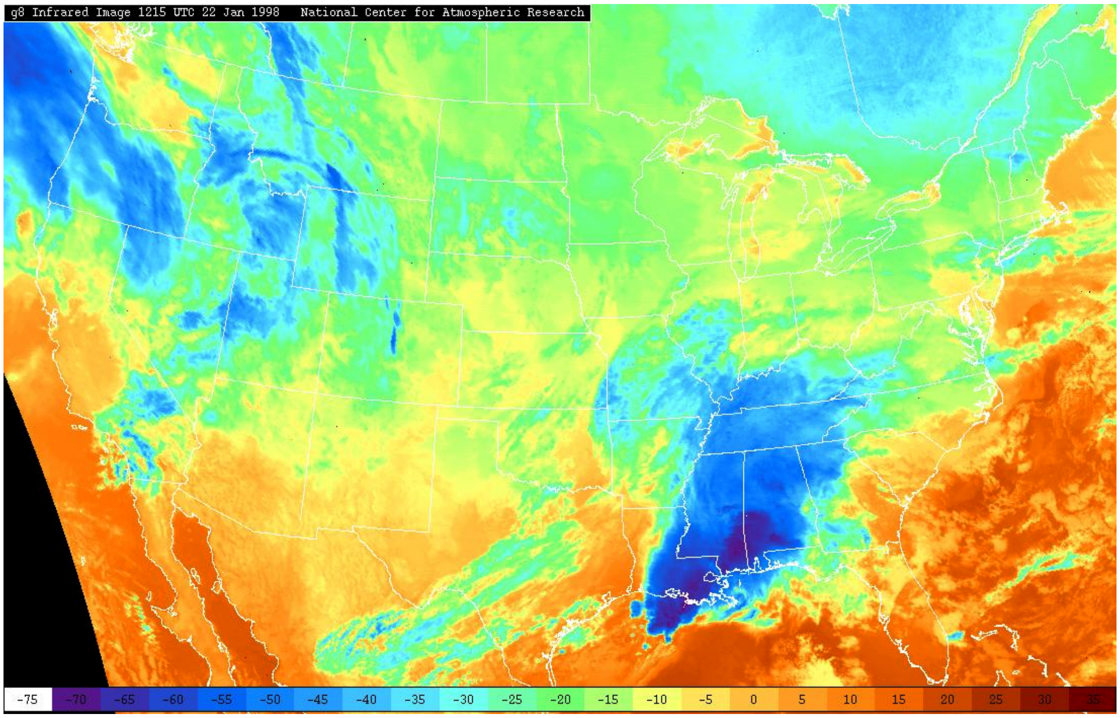
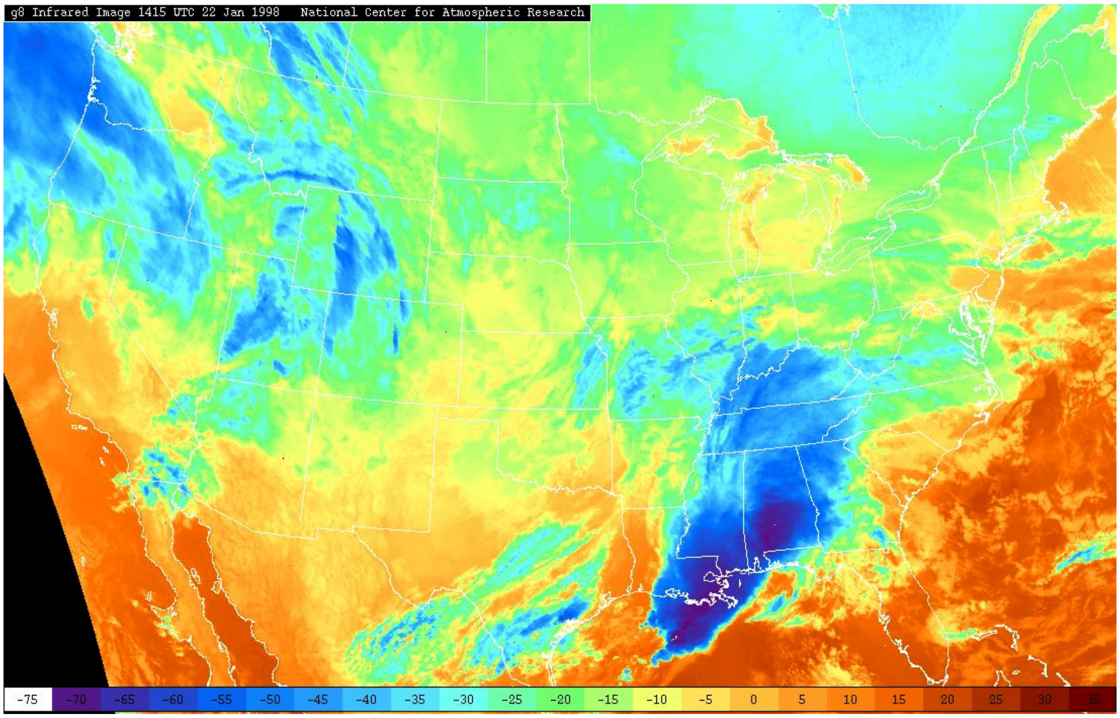


Figure 4 – GOES-8 infrared satellite image for 980122, 1215 UTC.



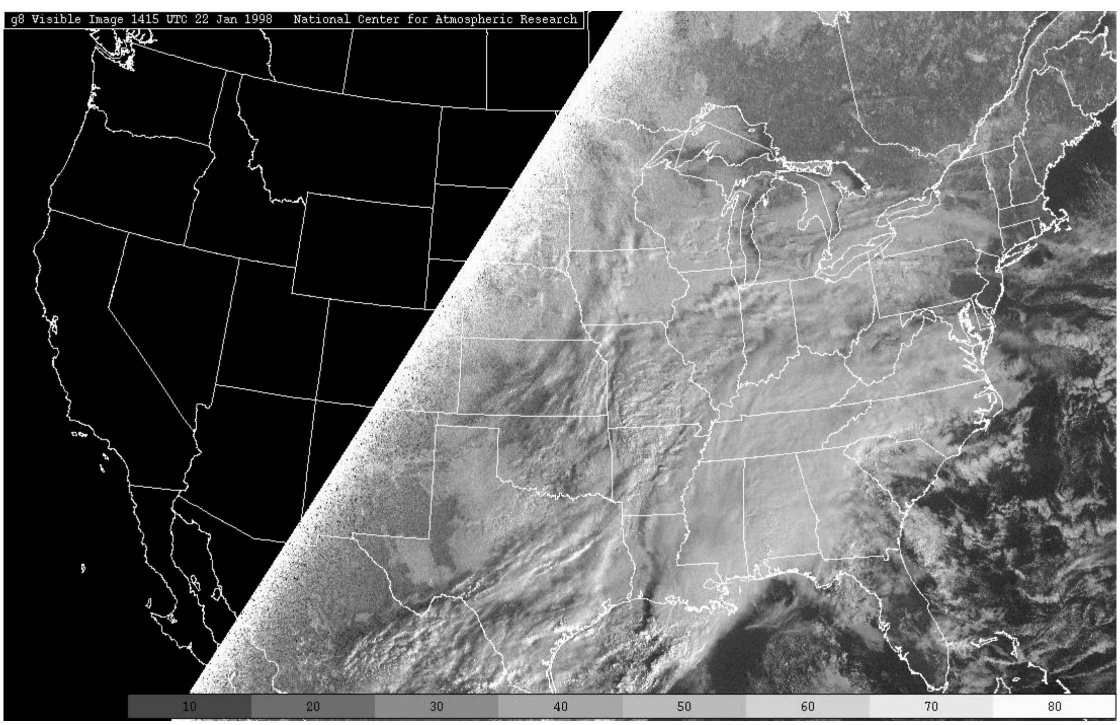
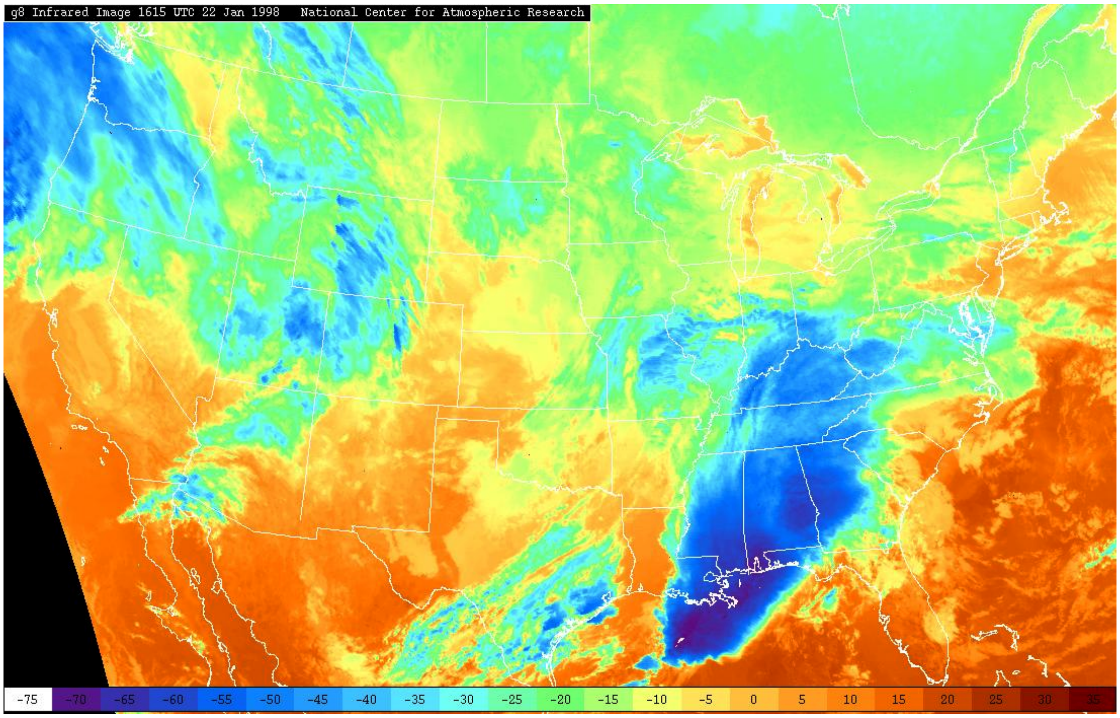


Figure 4 – GOES-8 b) infrared and c) visible satellite images for 980122, 1415 UTC.



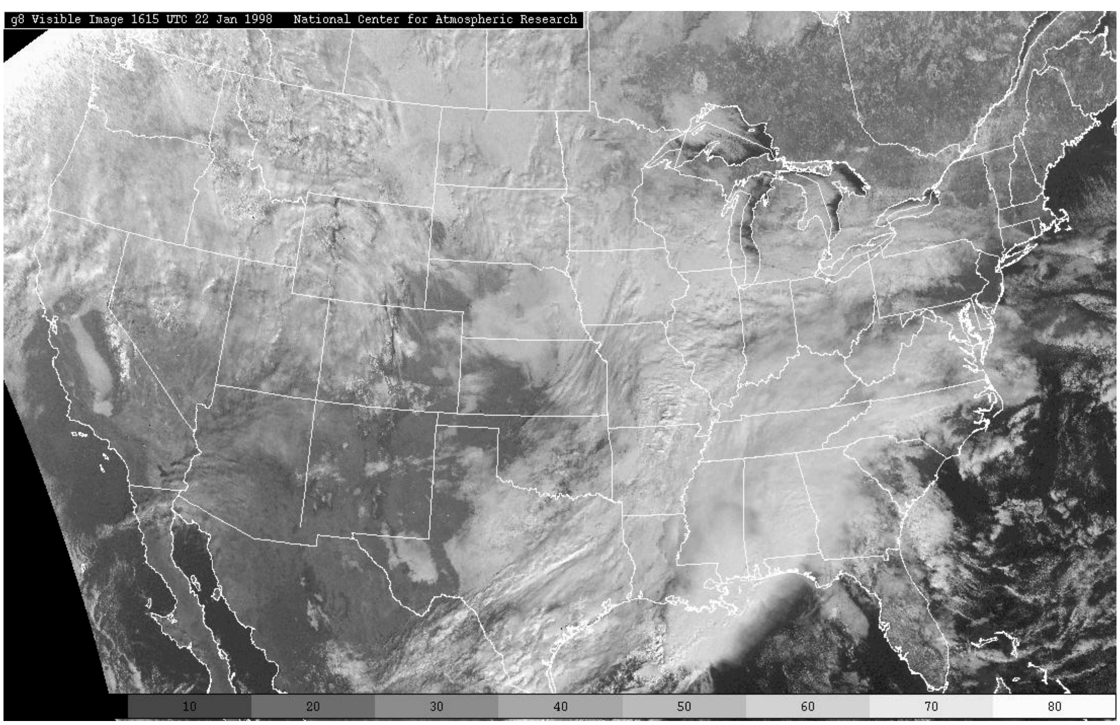
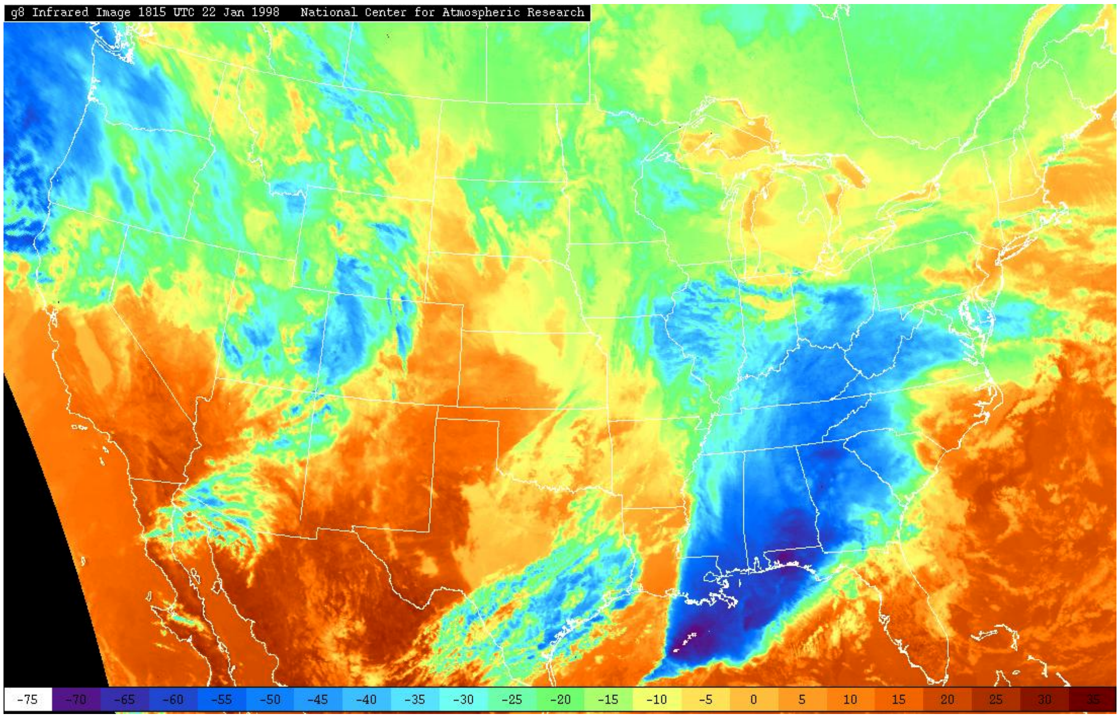


Figure 4 – GOES-8 d) infrared and e) visible satellite images for 980122, 1615 UTC.



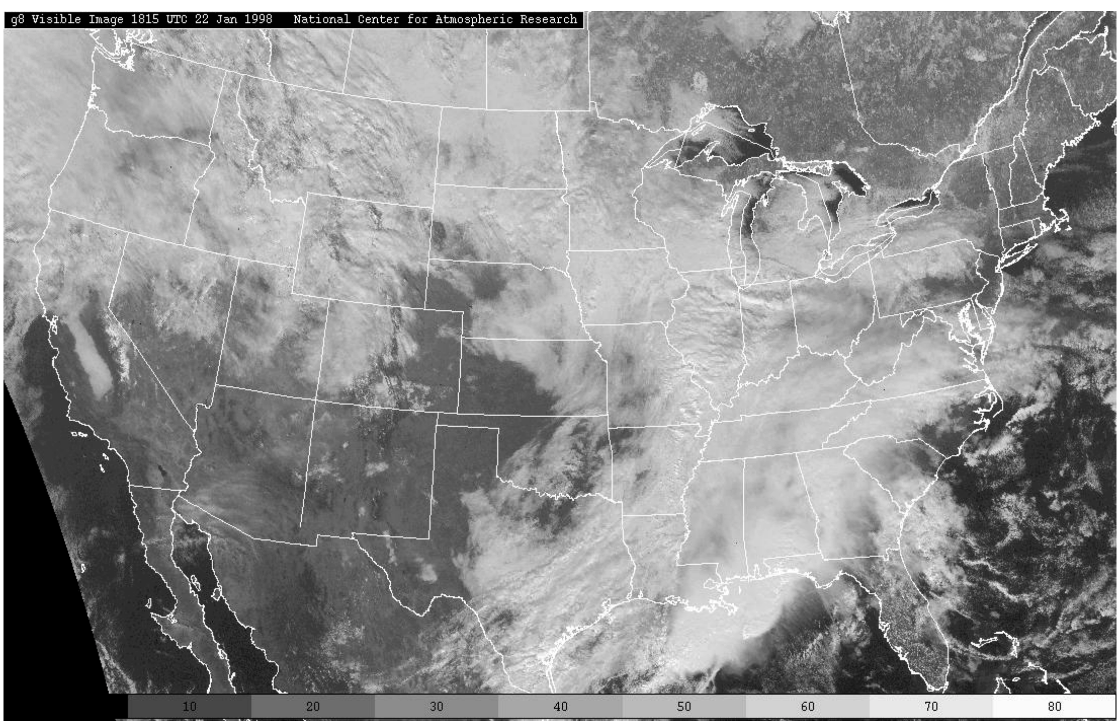
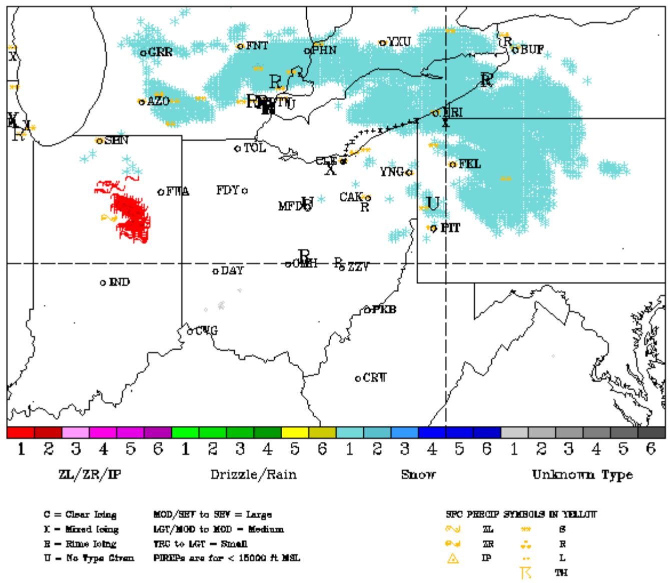


Figure 4 – GOES-8 f) infrared and g) visible satellite images for 980122, 1815 UTC.

RADAR DATA PLOT FOR 980122 AT 13 Z



RADAR DATA PLOT FOR 980122 AT 14 Z

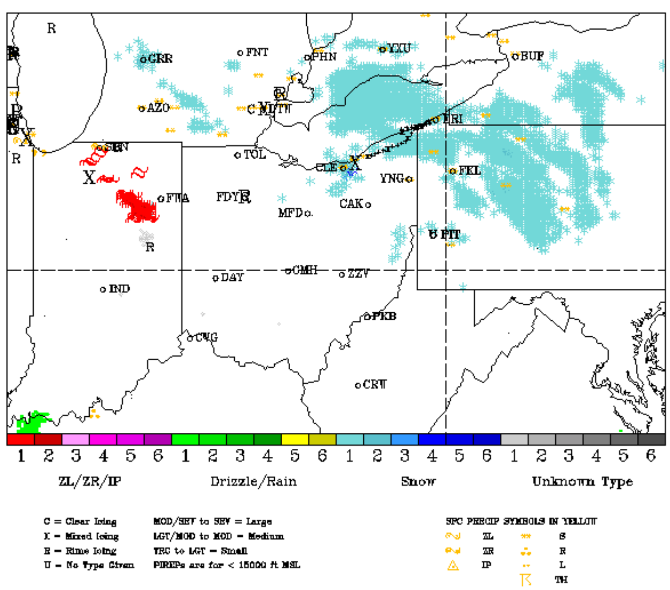
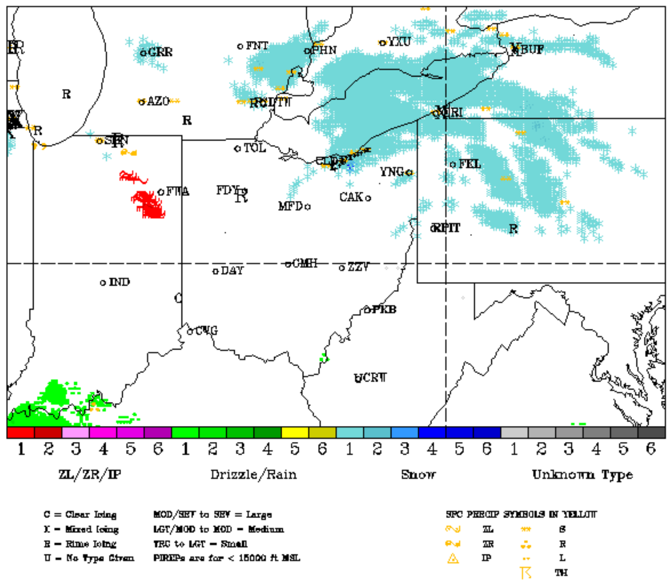


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980122, a) 1300 and b) 1400 UTC.

RADAR DATA PLOT FOR 980122 AT 15 Z



RADAR DATA PLOT FOR 980122 AT 16 Z

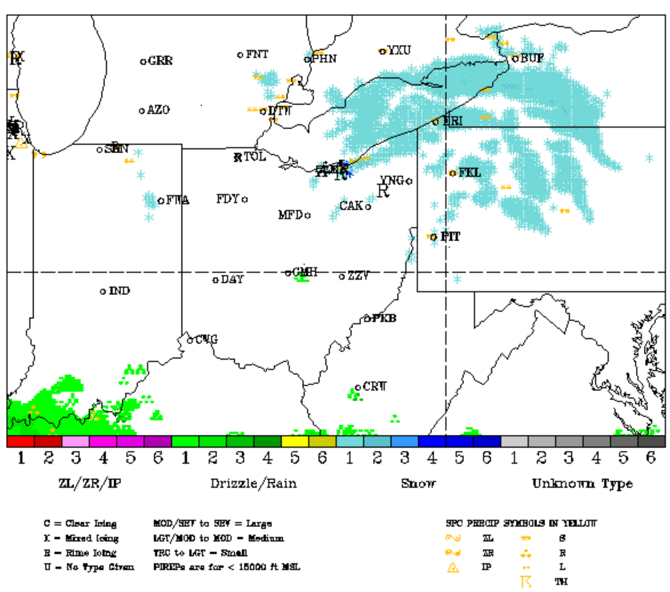
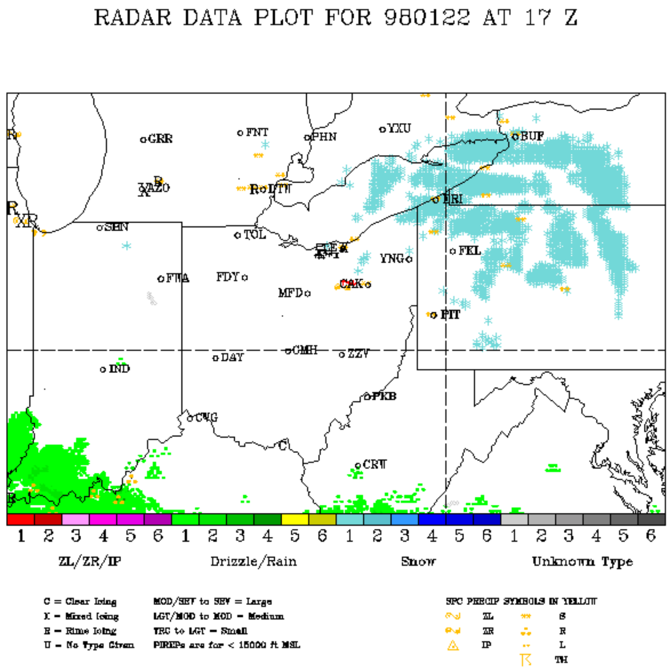


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980122, c) 1500 and d) 1600 UTC.



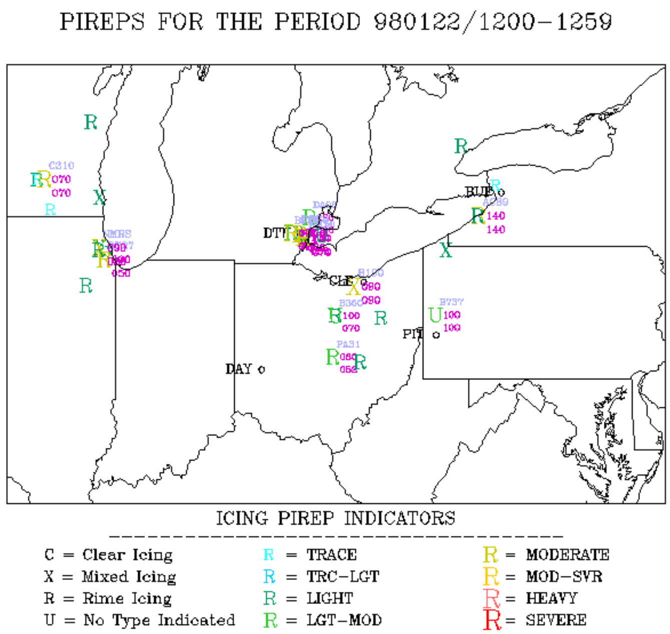
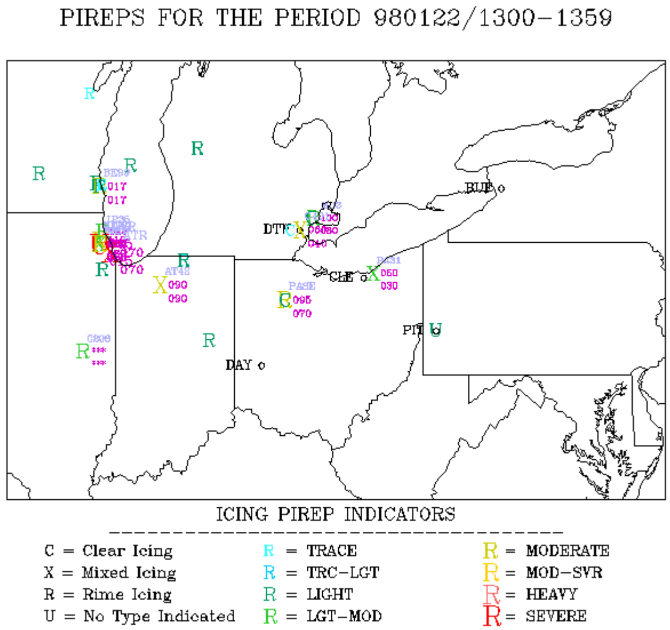


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980122, e) 1700 UTC.
Figure 6 – Pilot reports of icing for a) 980122, 1200-1259 UTC.



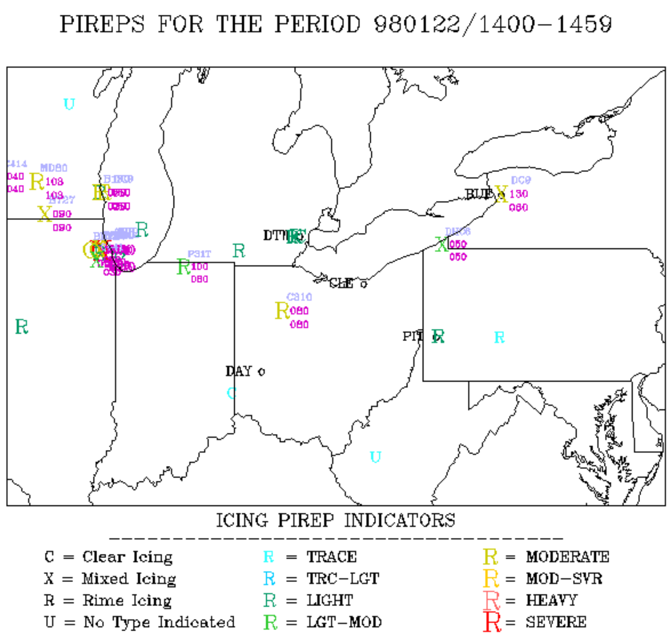
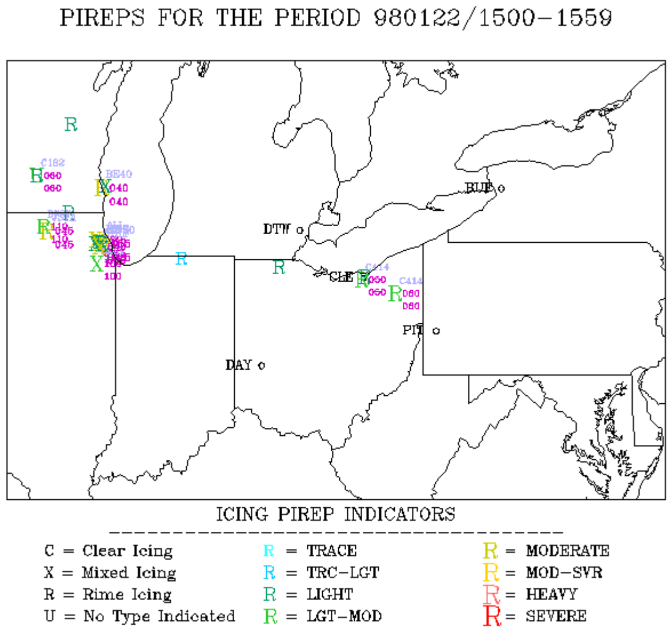


Figure 6 – Pilot reports of icing for 980122, b) 1300-1359 and c) 1400-1459UTC.



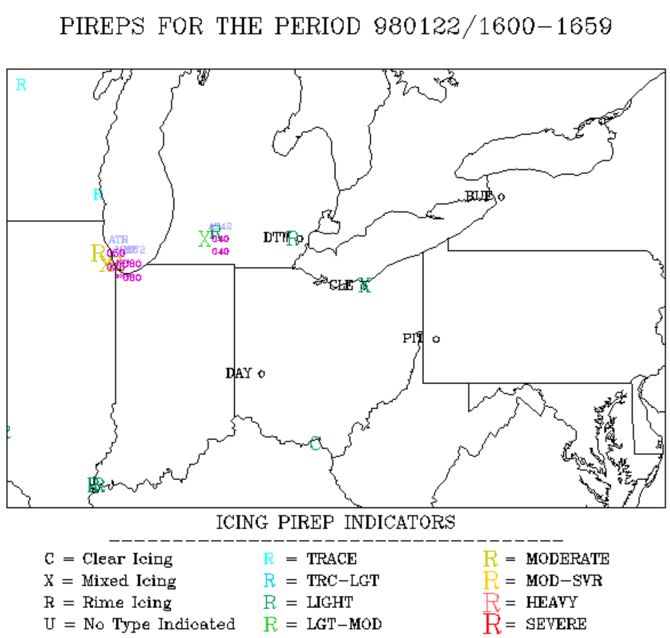


Figure 6 – Pilot reports of icing for 980122, d) 1500-1559 and e) 1600-1659UTC.

January 26, 1998

Flight #1—Ferry from Cleveland, OH, to Muskegon, MI, from 1339 to 1523 UTC.

Flight #2—From Muskegon, MI, to Green Bay, WI, from 1642 to 1851 UTC.

Flight #3—Over Green Bay, WI, and western Lake Michigan from 1956 to 2156 UTC.

Flight #4—From Green Bay, WI, to Lansing, MI, from 2251 to 2359 UTC.

Flight #5—From Lansing, MI, to Cleveland, OH, from 0106 to 0212 UTC.

Brief overview

A total of five flights were made during this event. The first flight was essentially a “hop” flight across southern Michigan to Muskegon, made along the southern end of a swath of light snow. Multiple cloud layers were encountered, with the main deck at around 11000’. This cloud contained LWC as high as 0.15, had temperatures near –15C, and often (but not always) contained ice crystals. Snow was observed beneath this cloud. On descent into Muskegon, multiple cloud decks were sampled, including a fairly thin one that had LWC of 0.3, and temperatures around –5C near 5000’.

Things got more interesting beginning with the second flight, as the Twin Otter crossed Lake Michigan (LM) to reach eastern Wisconsin. Multiple cloud decks that were nearly all water were sampled across the eastern part of LM on initial ascent through 6000’. After descending, freezing drizzle (ZL) was first encountered at 3700’ (T = -4C), beneath a ~1000’ thick cloud deck over LM. Some crystals were mixed with the ZL and cloud droplets at times. Upon reaching eastern Wisconsin, pockets of small-drops, ice crystals, ZL, and mixtures thereof, were sampled between 2000’ and 2800’ over Sheboygan, Manitowoc, and southeast of Green Bay (GRB). LWC fluctuated wildly between 0.0 and 0.4, while T was near –4C during this portion of the flight (through about 1800 UTC). The variable conditions continued near GRB, but extended periods of in-focus ZL without crystals were observed below ~4500’, with LWC up to 0.3, and temperatures of –4 to –7C. The top of the lower cloud deck at GRB was near 6700’, with CTT of –6C, but more cloud layers existed above this level.

The third flight began with a climb through several cloud decks over GRB, the lowest of which had ZL beneath and within its bases, extended from 1100’ to 6200’, had LWC up to 0.35, and CTT of –7C. Other thin decks were found, with the highest extending from 9200’ to 10700’, with CTT of –14.5C, LWC up to 0.2, and some crystals mixed with the small drops. The Twin Otter descended, then did a series of NE-SW transects over Green Bay (the water body) from 5000’ down to 2300’, finding small drops at 5000’ and increasing drop sizes with decreasing altitude, including in-focus ZL below ~4000’. Conditions remained variable, with intermittent ZL, occasional crystals, and LWC fluctuating from 0.15 to 0.45. ZL was observed at altitudes as high as 7200’ and T = -8C just SW of the shoreline of Green Bay at 2104 UTC. The Twin Otter flew southeast toward Manitowoc, finding only small drops and a few crystals there, but hit a narrow band of LWC to 0.6 (LWC was only 0.15 nearby) along the western shore of Lake Michigan at 3800’. The aircraft returned to GRB, finding only small-drop conditions en-route, and some in-focus ZL mixed with crystals upon landing at GRB.

The fourth flight was essentially a ferry to Lansing MI on the way home, but interesting conditions were sampled. Small droplets and some crystals were found near GRB, and some in-focus ZL with temperatures near –10C, and LWC < 0.1 were observed from 8000' to 8800' near Manitowoc WI. Occasional crystals (dendrites) were mixed in at times. The ZL was observed until the Twin Otter was halfway across LM, and mostly small drops, with a few brief patches of ZL and an occasional crystal were observed between 8800' and 10000' after that. LWC was as high as 0.2 in the clouds over the eastern half of LM, with T = -13C at 10000'. No particles were observed east of LM as the aircraft continued to Lansing. The fifth flight was made in clear air at 6600' between Lansing and Cleveland.

Relevant weather features

At 1200 UTC, a north-south trough was in place at 300 mb from Minnesota to eastern Texas, with southwesterly flow ahead of it (Fig. 1). No jet dynamics were occurring in the forecast area. The trough was also present at 500 mb, and connected to a weak, closed low along the Texas/Oklahoma border. There was a swath of the saturated conditions with temperatures of -27C from central Canada into northern Wisconsin and northern Michigan. Dry air was nearby in Iowa and southwestern Wisconsin, as well as over southern Michigan and northern Ohio, while a band of moisture existed to the south of the forecast area, from southern Illinois to Virginia. The closed low was slightly stronger at 700 mb, and the trough remained. Weak warm advection and southwesterly flow was occurring over northern Minnesota, Wisconsin, and Michigan. Saturated conditions were more widespread at this level, covering the entire forecast area, except for a pocket of dry air over central Illinois and western Indiana. The low/trough pattern continued at 850 mb, though an east-west oriented trough was now evident across northern Iowa, southern Wisconsin and central Michigan. Winds were westerly and conditions were relatively dry to the south of the trough, while winds were southeasterly to the north of the trough and conditions were saturated (T = -8C at Green Bay, -10C at Alpena, and -7C at Detroit) along and to its north. Those saturated conditions extended across Detroit and Cleveland, but were not present in southwestern Ohio. Warm advection was very evident across the forecast area.

By 0000 UTC, the low/trough pattern shifted slightly eastward, with the 500 mb low centered over southeastern Arkansas, and the trough running northward to the Minnesota/Wisconsin border (Fig. 2). Dry conditions were present across Minnesota, Wisconsin, Michigan, and northwestern Indiana, while a patch of moisture was moving northward into southern Ohio. Weak cold advection was evident across southern Michigan and northern Illinois. Saturated conditions (T ~-12C) continued across most of the forecast area at 700 mb, while warm advection was present only across Wisconsin, Illinois, and extreme southern Ohio/Indiana. Dry air was present in eastern Ohio. At 850 mb, the dry air was very evident across parts of southern Ohio and Indiana, while saturated conditions and warm advection persisted over Michigan and Wisconsin. The east-west trough persisted across southern Wisconsin, but seemed to be weaker over southern Michigan by this time.

The 1200 UTC surface map (Fig. 3) indicated a stationary front from North Dakota across southern Wisconsin and southern Michigan to Massachusetts, with a 1034 mb high over southern Ontario.

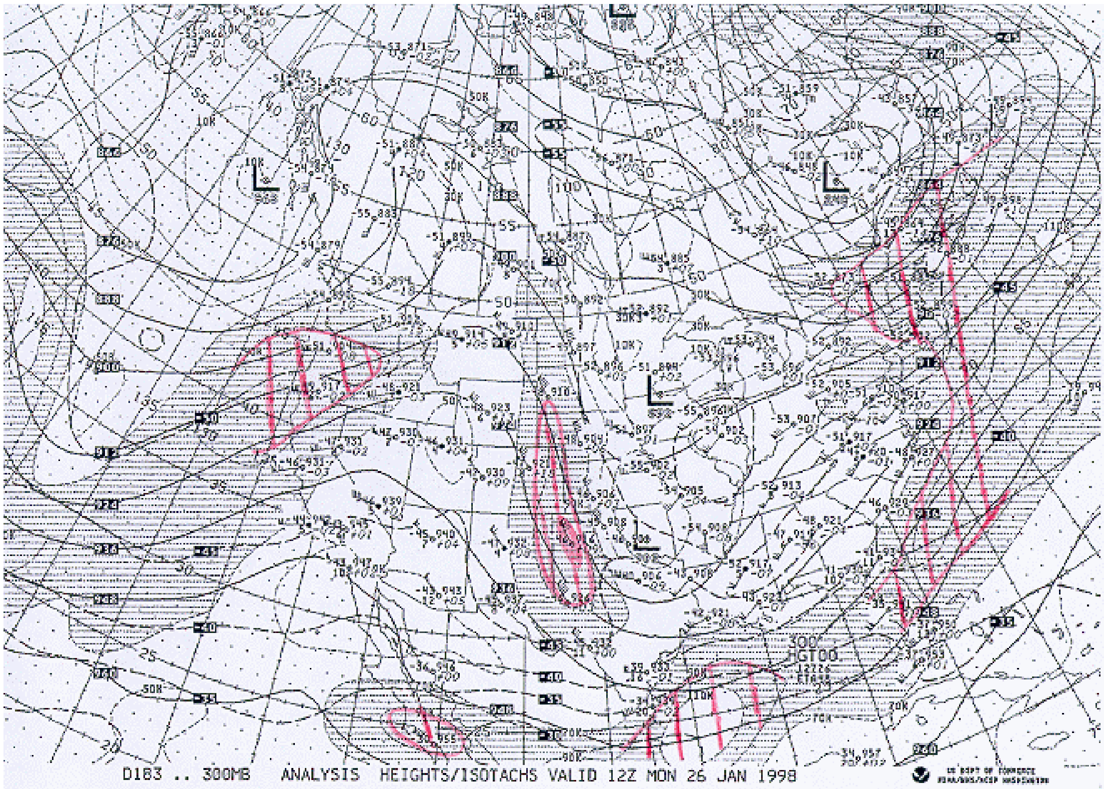
Snow, easterly and northeasterly winds were present to the north of the front, while southeasterly winds and pockets of cloud and clear skies were present its south. Localized northeasterly winds at Green Bay were observed at 1800 UTC during the freezing drizzle event sampled there. These winds turned to easterly and the precipitation changed to snow there by 2100 UTC. Easterly winds that blew across Lake Michigan made the western shoreline the favorable downwind side for lake-effect cloud formation. The 0000 UTC surface map showed a weak low developing in southern Iowa, while the high-pressure center pushed eastward into northern New York state.

The 1200 UTC Detroit sounding (Fig. 4) showed saturated conditions up to ~800 mb, with cloud top temperatures near -8C, and a bit of cloud near 700 mb. The Twin Otter flew between these cloud decks when it passed over Detroit, and briefly hit the thin upper deck just west of Detroit. A sharp transition in wind direction was present near the lower cloud top, marking the upper trough found on the 850 mb chart. The 1200 UTC Green Bay sounding also had a wind shift near 800 mb, but had another near 960 mb. Winds were from the northeast (off Green Bay, itself) below a strong inversion and were from the southeast (from Lake Michigan) above that, then from the southwest above the inversion at 800 mb. A third inversion was present near 650 mb and saturated conditions were clearly present to this height. Moisture continued to 500 mb, but the balloon was likely to have been well northeast of Green Bay at this height, where somewhat deeper, colder clouds existed. Green Bay was located on a gradient in cloud top temperature and precipitation, as will be revealed in the satellite and radar data. By 0000 UTC, the Green Bay sounding became less complex, with cloud from near the surface to 670 mb, and a cloud top temperature of -14C or so. One inversion was present just above 850 mb, and veering winds found below this level marked the warm advection there. A similar structure was present at Detroit, with a deeper inversion, but conditions that appeared to be shy of saturation. This matches a pocket of clear skies that was evident in the satellite data and surface observations just to the south of Detroit after 1400 UTC.

Infrared and visible satellite data for 1415 UTC (Fig. 5) show clouds across Wisconsin and Michigan, with clear skies to the north, and patches of clear skies over Indiana and Ohio. CTTs over southern Michigan were about -20C, and about -15C over most of Wisconsin. A swath of CTTs < -30C existed across northern Michigan and just north of Green Bay. Light snow was falling over areas with CTTs < -15C or so, to the north of a line from Sheboygan (SSE of Green Bay) to Jackson MI (see radar mosaic data in Fig. 6). During the first flight, the Twin Otter flew northwestward just to the south of that line. By 1815 UTC, CTTs warmed over central Michigan and near Green Bay, and the snow moved northward with the colder CTTs. Although automated surface stations around Green Bay reported only light snow through 1800 UTC, the Manitowoc County Sheriff's department and the public reported freezing drizzle to the southeast of Green Bay and at Manitowoc. The Twin Otter found both freezing drizzle and snow aloft in this area. Green Bay reported freezing rain (rather than the freezing drizzle that was actually occurring there) at 1800 UTC (and at earlier times), due to ASOS problems. At 2000 UTC, radar data indicate that Green Bay was on the edge of the reflectivity, while satellite data indicated CTTs near -15C. An area of warmer CTTs was in place over southern Wisconsin, southern Lake Michigan, and western

Michigan beginning around 1600 UTC. During the third flight (~2130 UTC), the Twin Otter flew near the edge of this feature, and seemed to enter it during the fourth flight (~2320 UTC).

A fair number of PIREPs of all intensities and types occurred between 1500 and 13,000 feet (Fig. 7). Of particular interest were several moderate severity rime, mixed, and clear PIREPs over eastern Wisconsin and southern Michigan. The eastern Wisconsin PIREPs were all at altitudes below 12,000 feet, with most between 4000 and 9000 feet. Many were from prop aircraft.



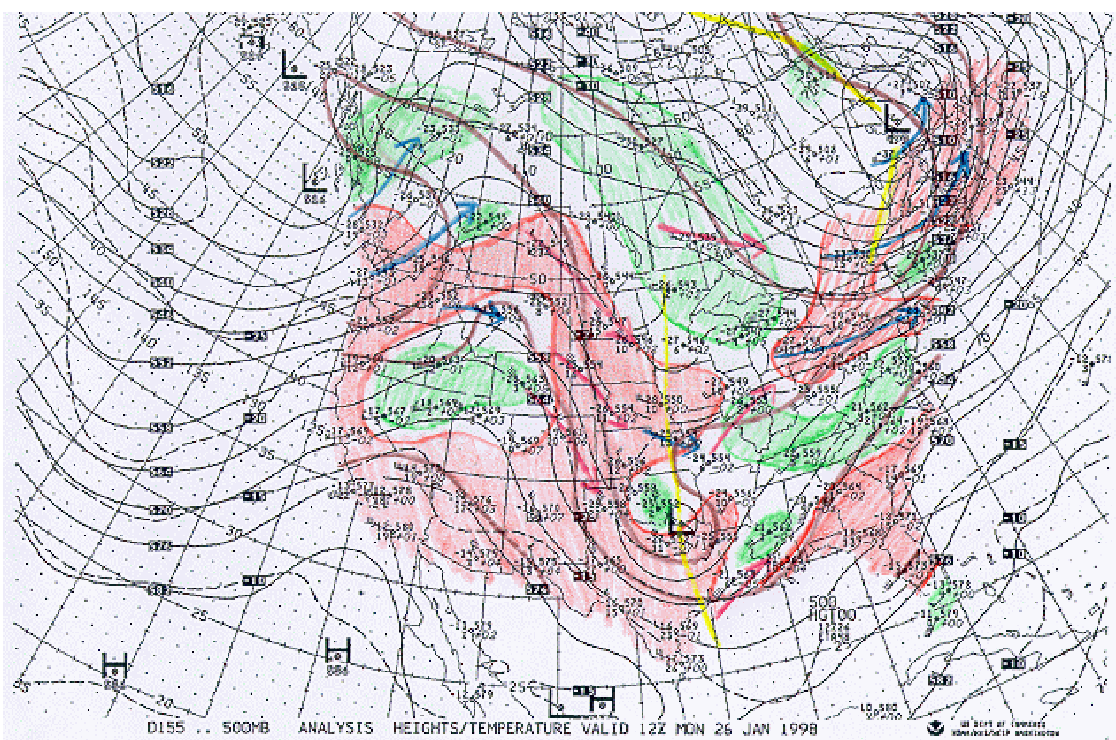
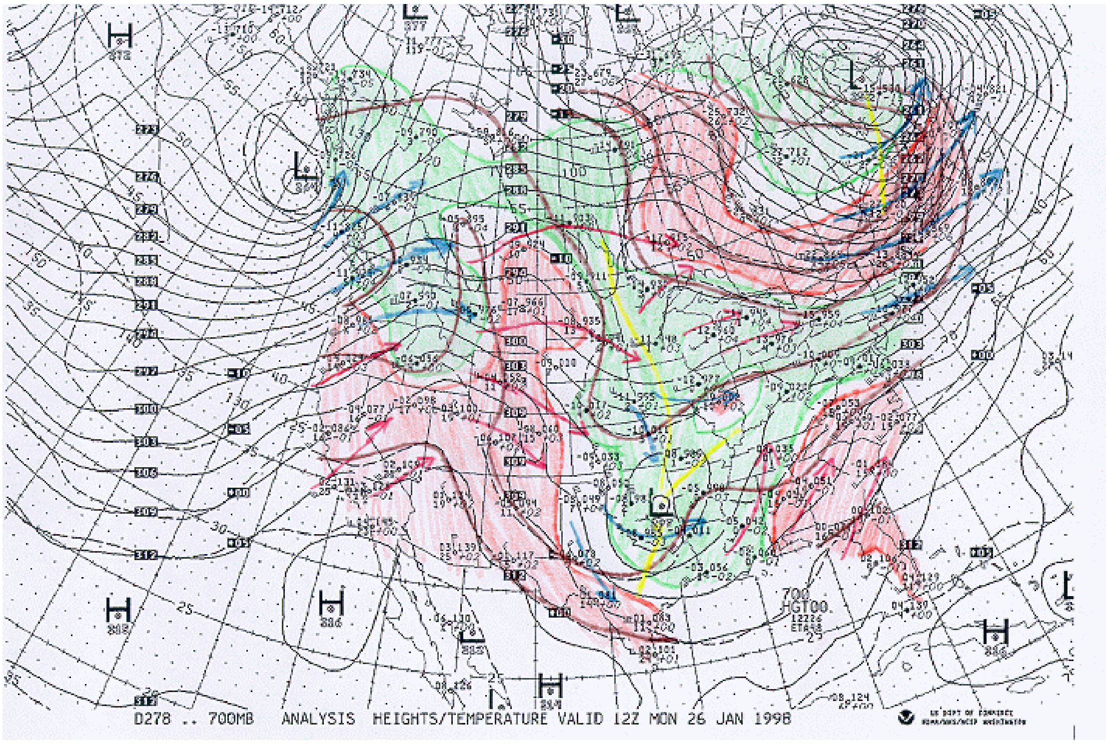


Figure 1 – Upper-air charts for 980126, 1200 UTC at a) 300 and b) 500 mb.



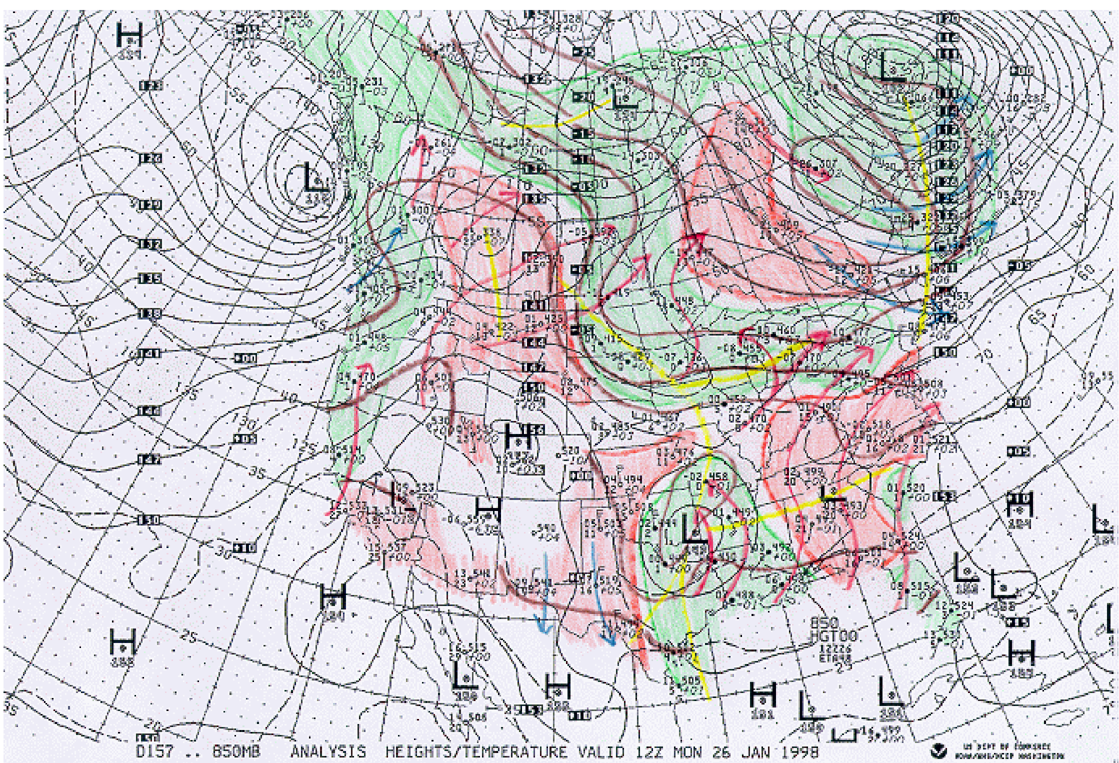
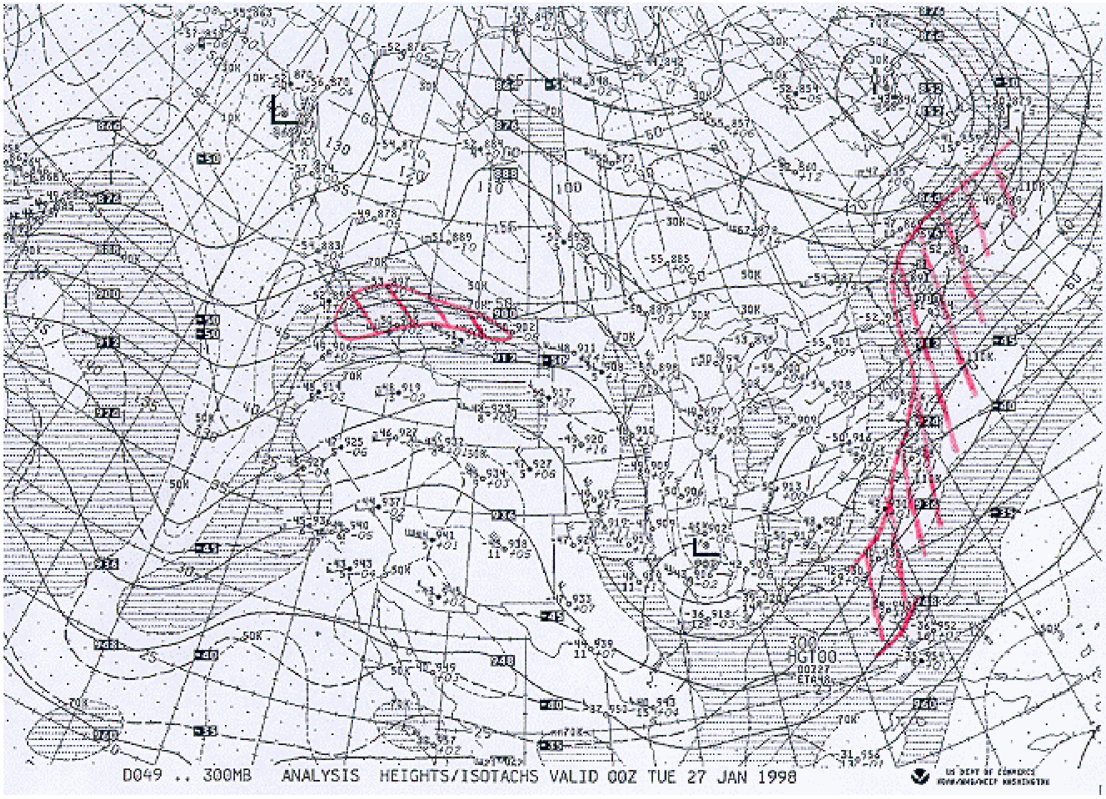


Figure 1 – Upper-air charts for 980126, 1200 UTC at c) 700 and d) 850 mb.



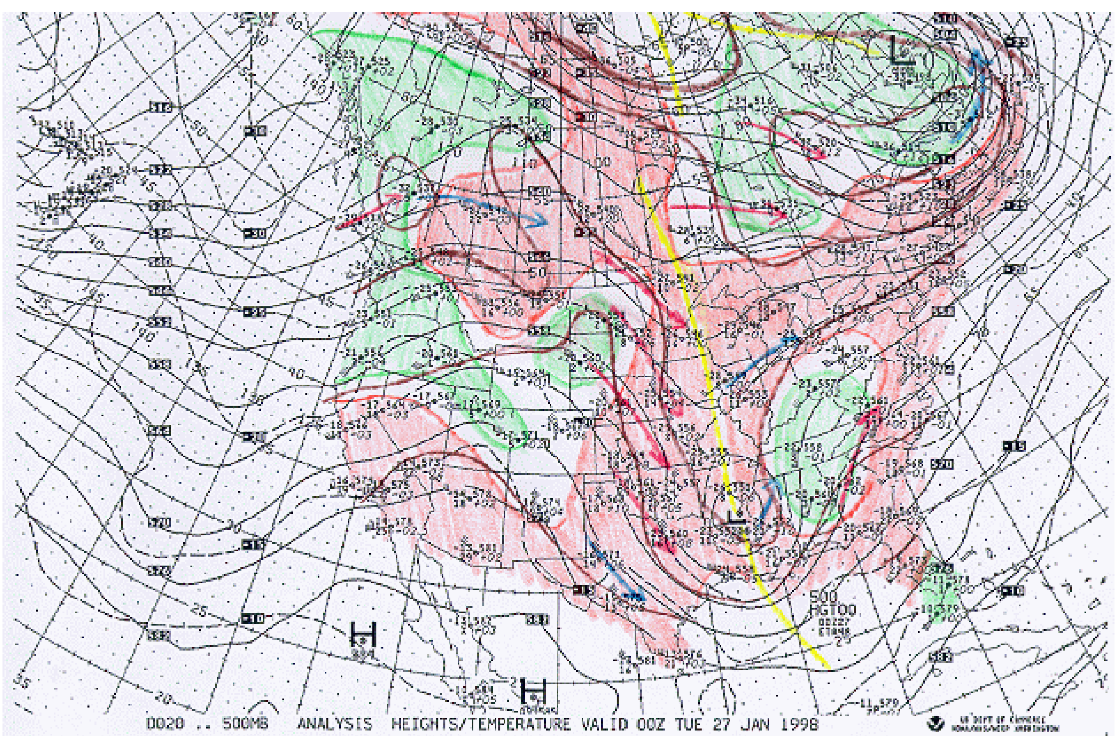
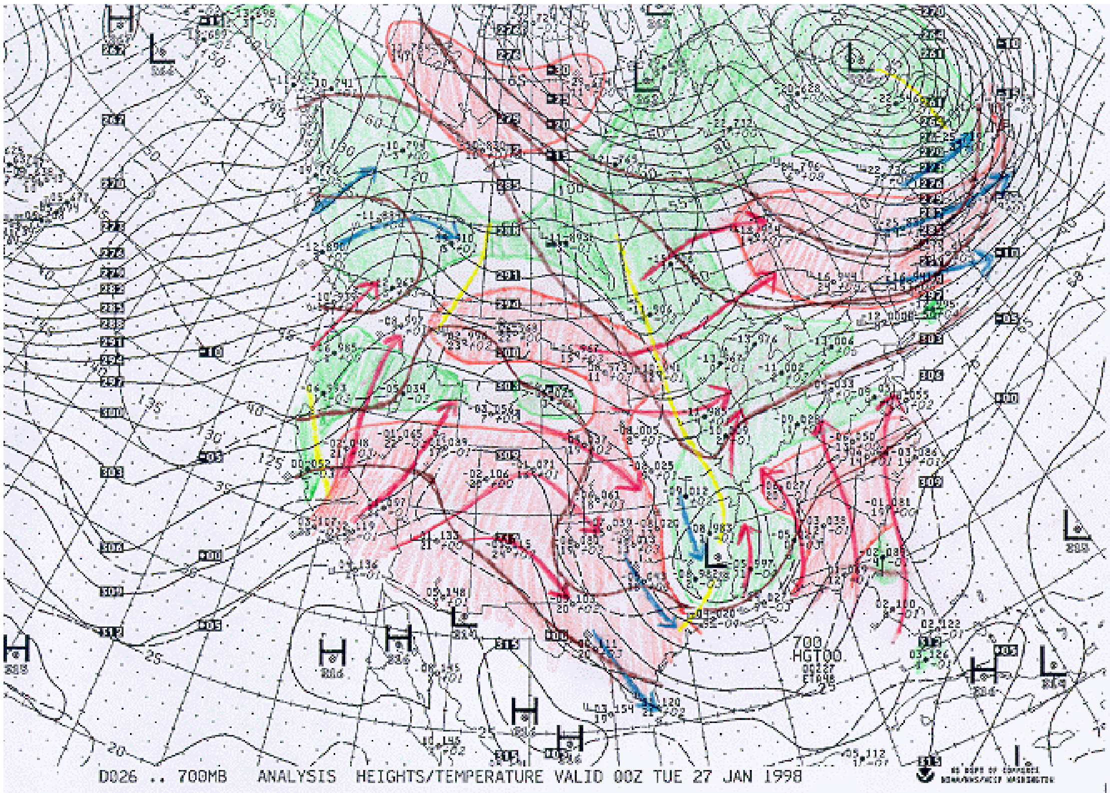


Figure 2 – Upper-air charts for 980127, 0000 UTC at a) 300 and b) 500 mb.



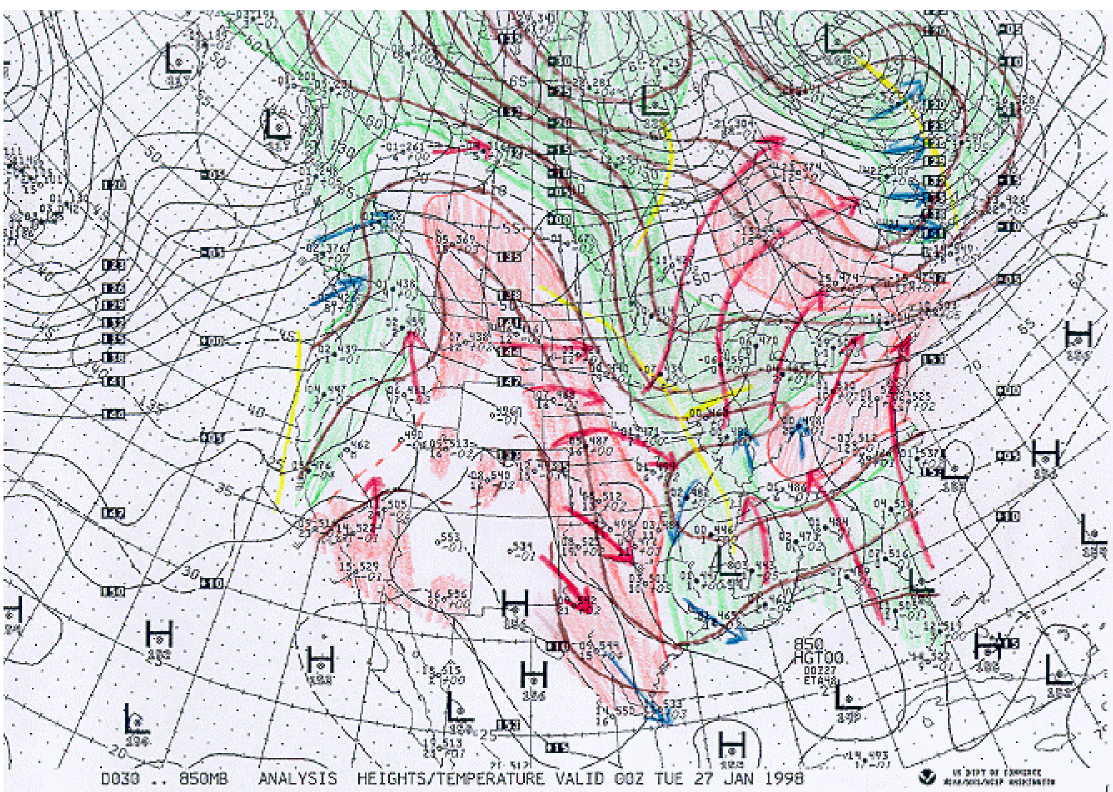
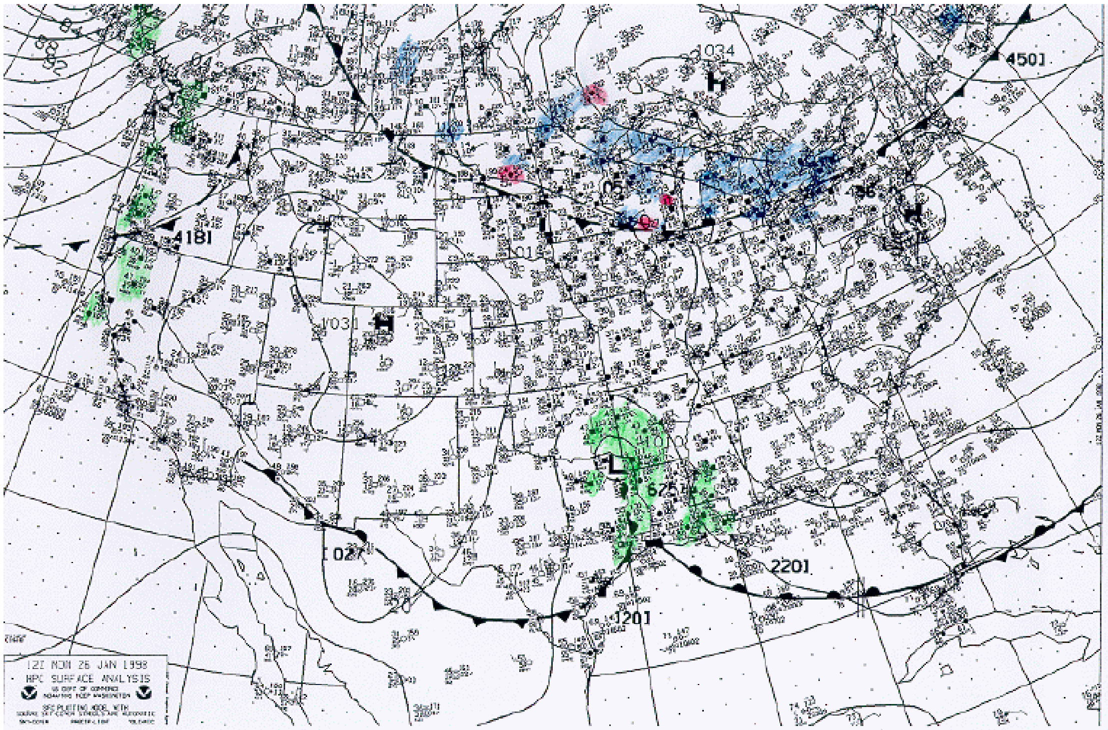


Figure 2 – Upper-air charts for 980127, 0000 UTC at c) 700 and d) 850 mb.



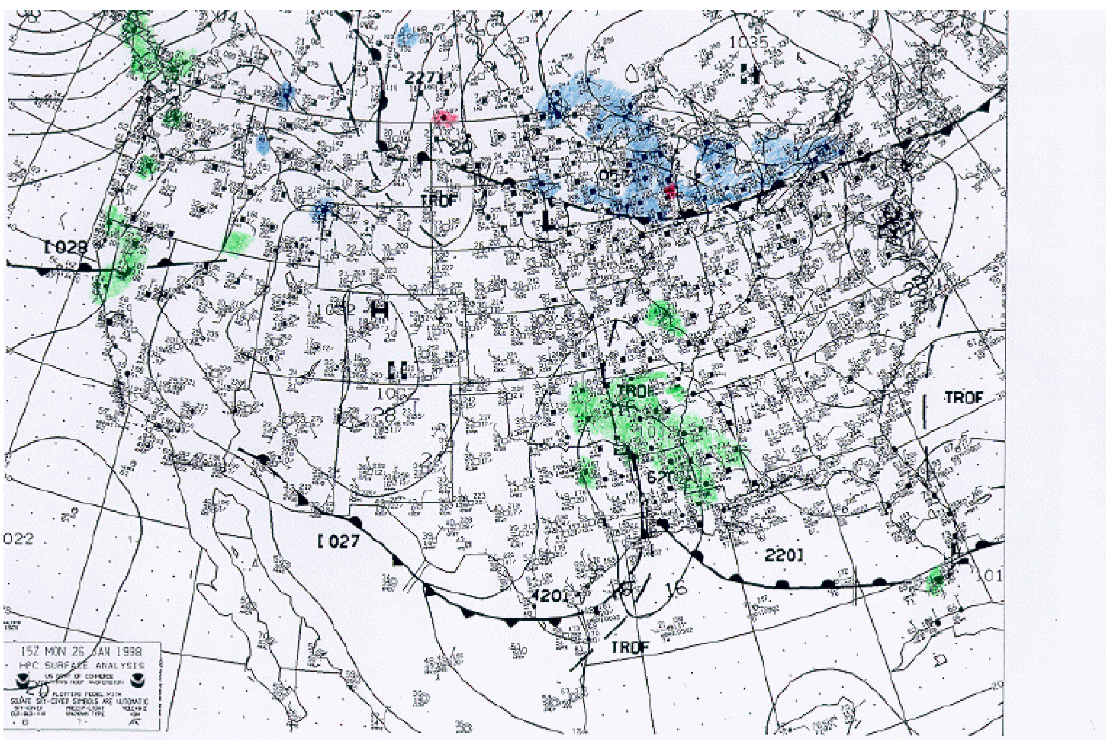


Figure 3 – Surface charts for 980126, a) 1200 and b) 1500 UTC.

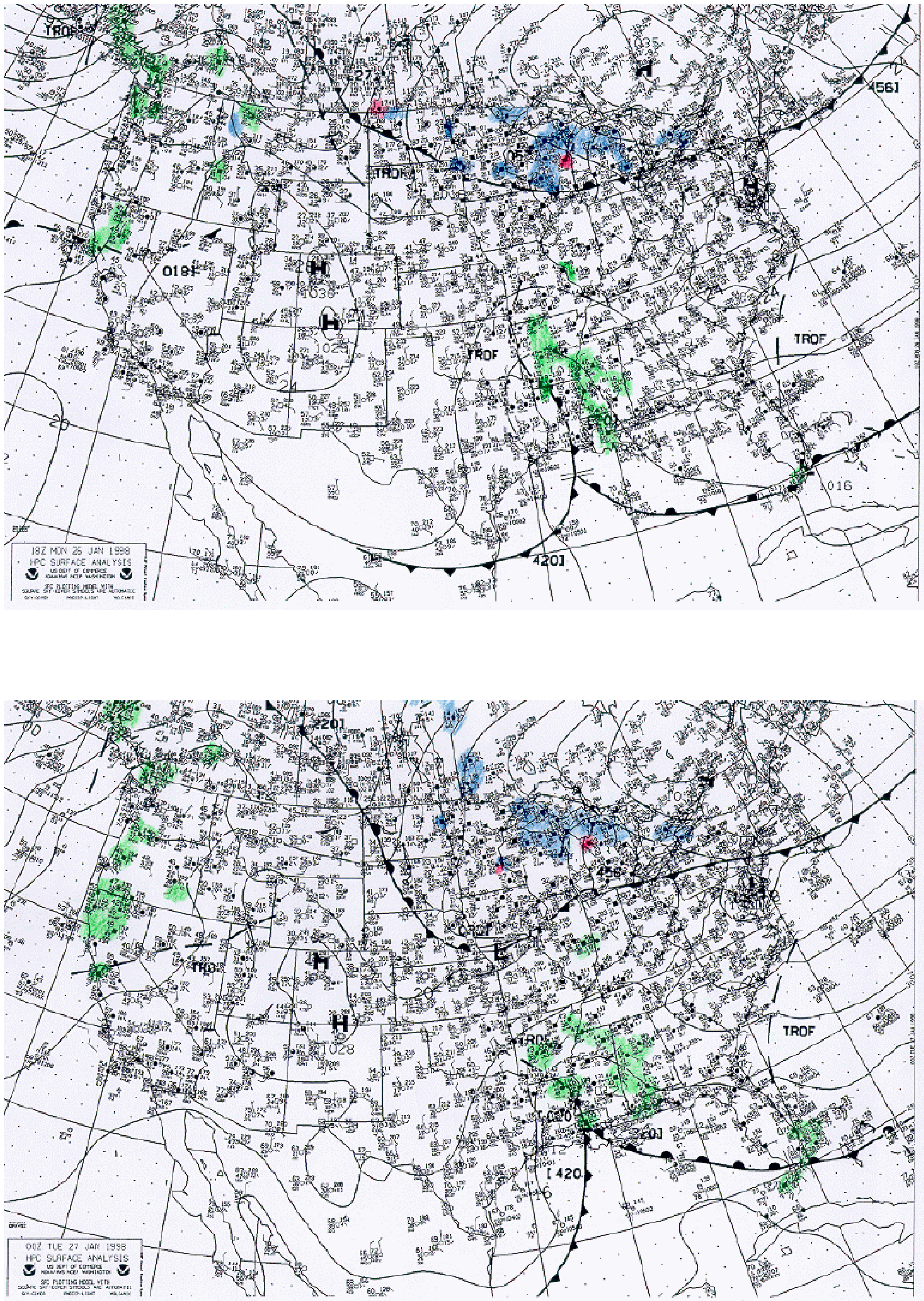
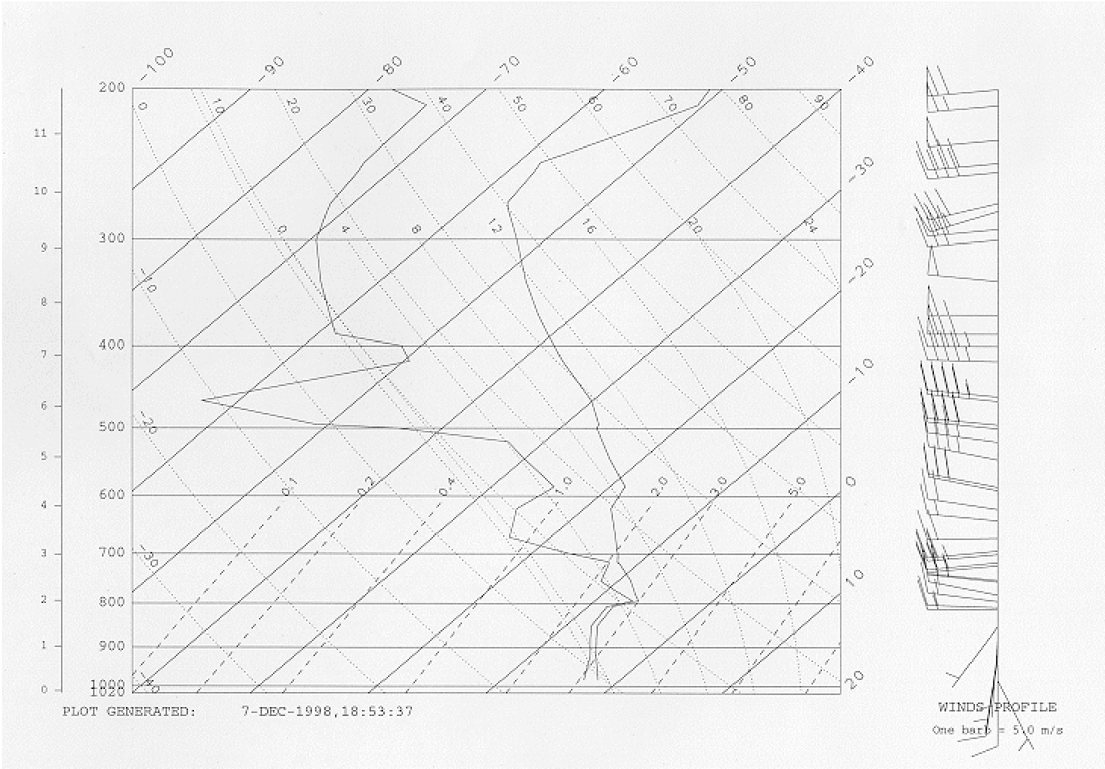


Figure 3 – Surface charts for c) 980126, 1800 and d) 980127, 0000 UTC.



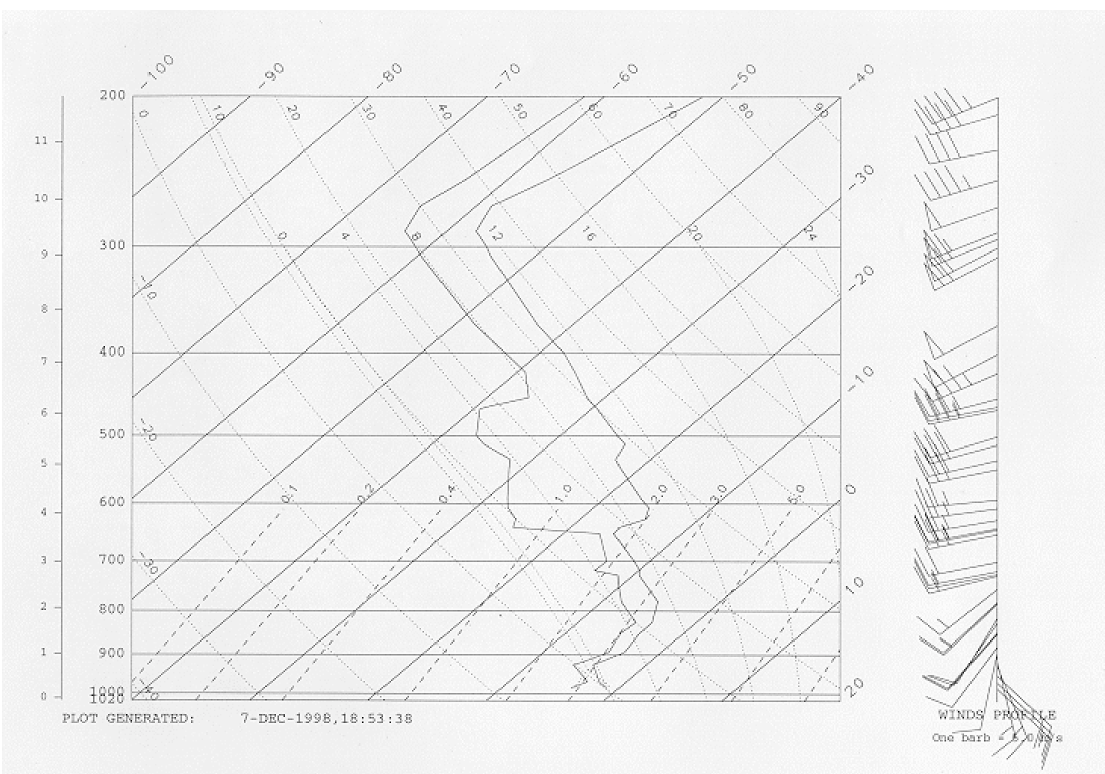
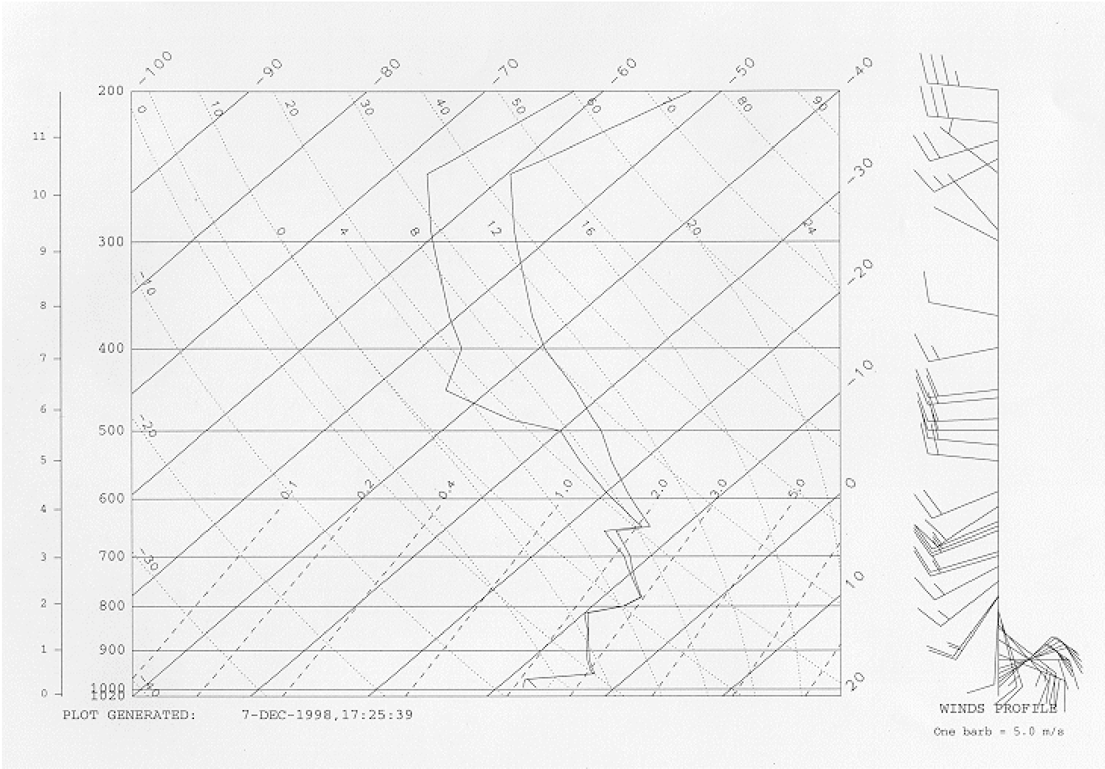


Figure 4 – Balloon-borne soundings from Detroit for a) 980126, 1200 and b) 980127, 0000 UTC.



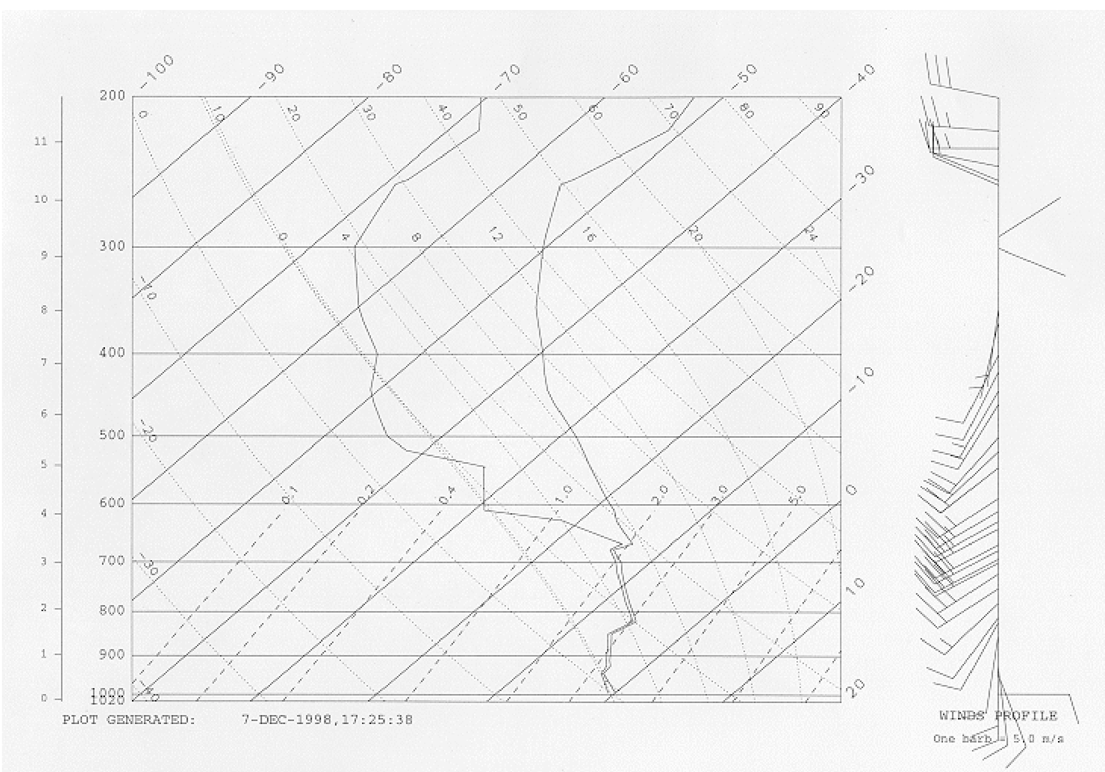
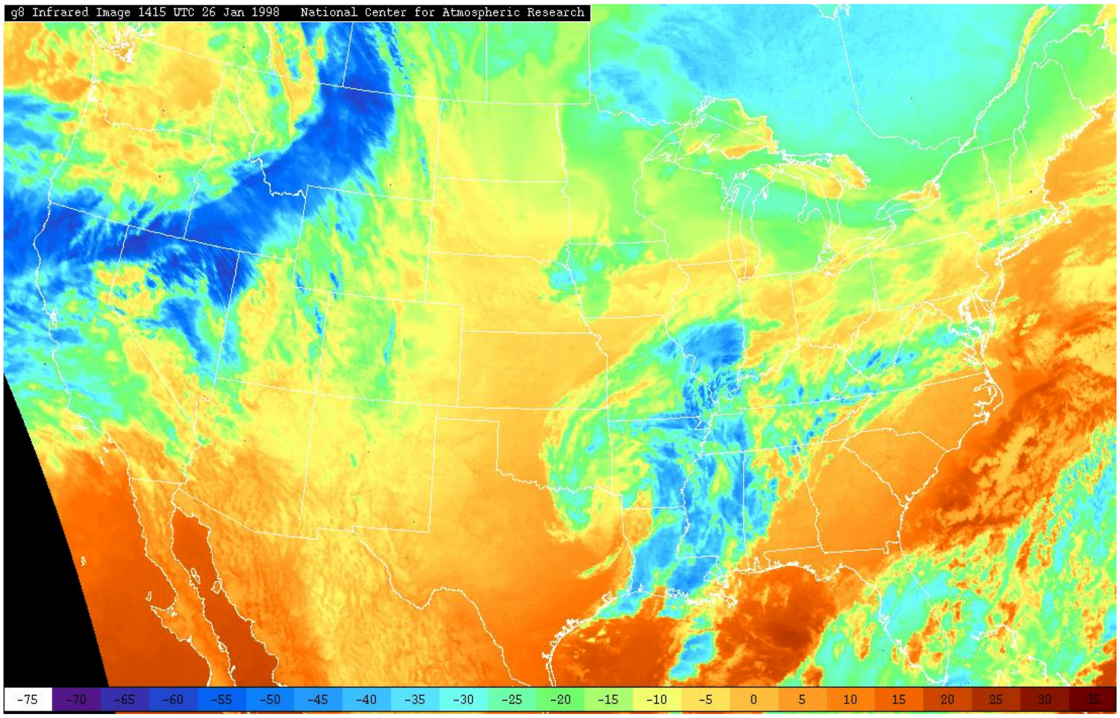


Figure 4 – Balloon-borne soundings from Green Bay for c) 980126, 1200 and d) 980127, 0000 UTC.



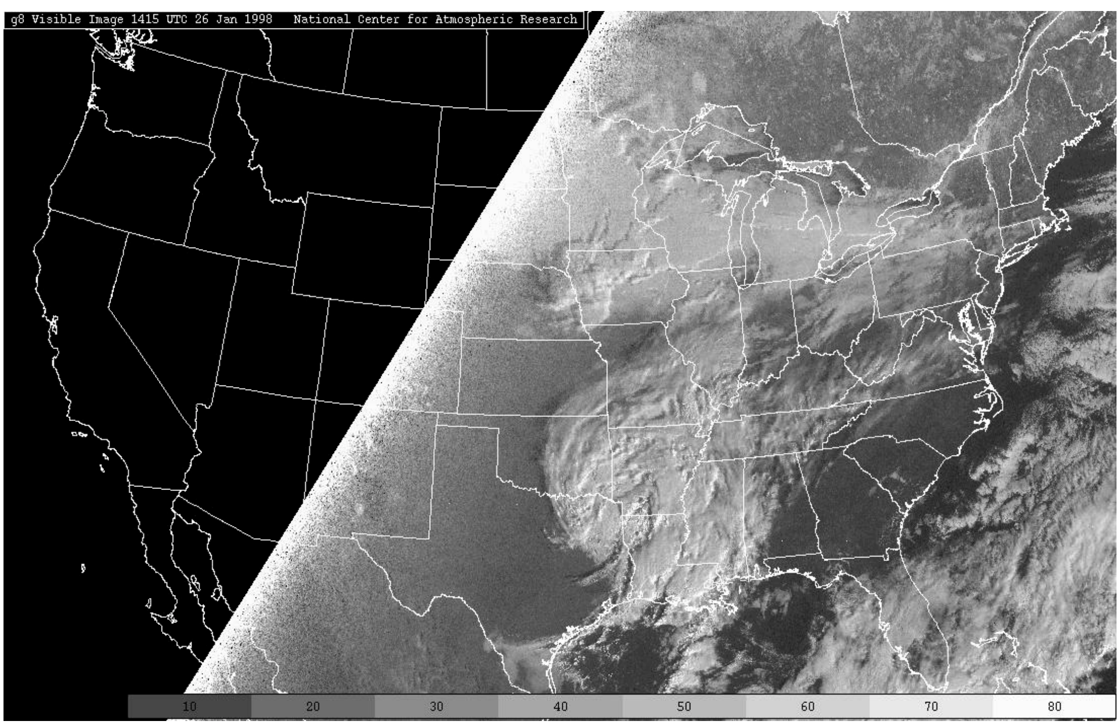
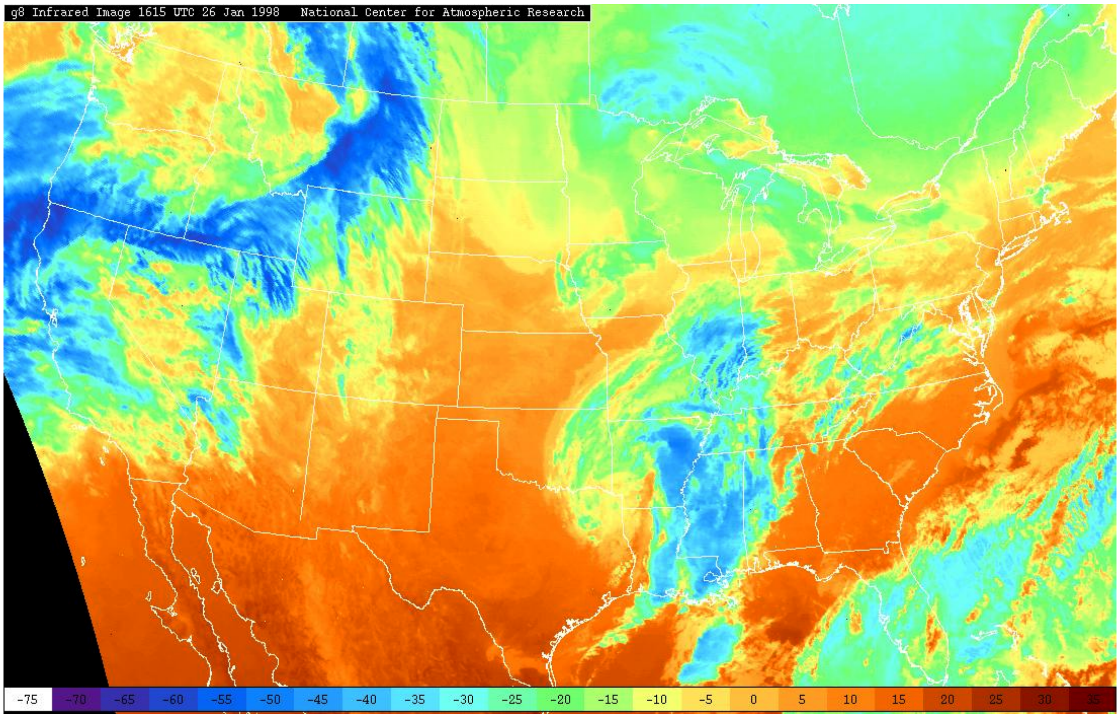


Figure 5 – GOES-8 a) infrared and b) visible satellite images for 980126, 1415 UTC.



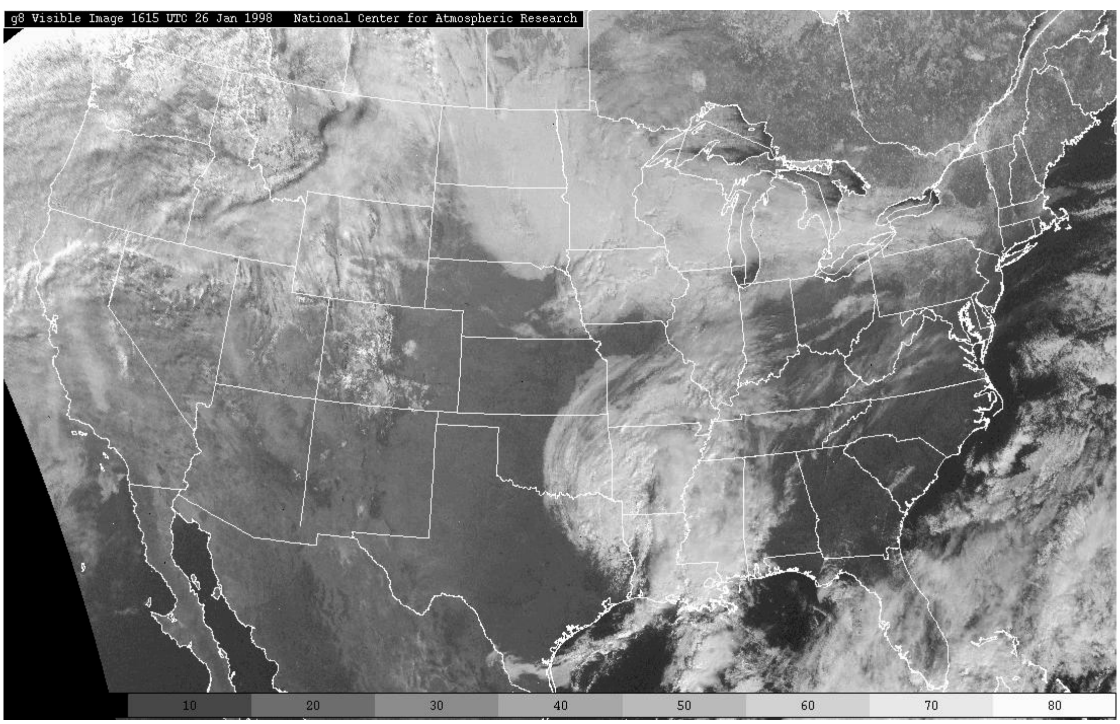
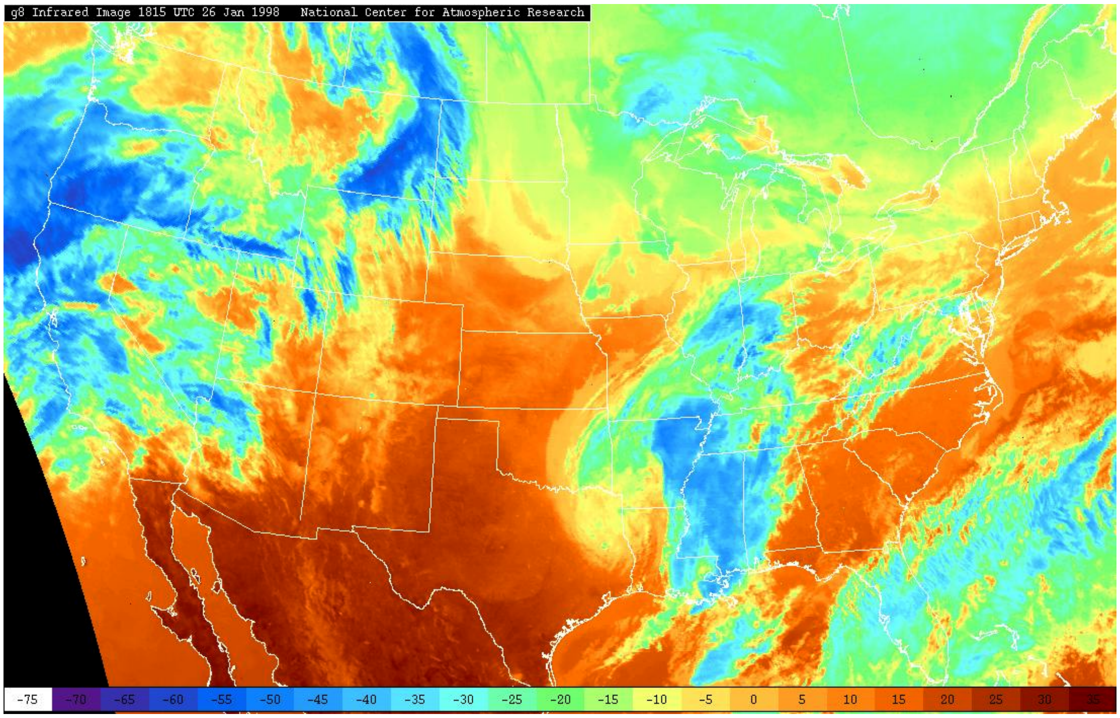


Figure 5 – GOES-8 c) infrared and d) visible satellite images for 980126, 1615 UTC.



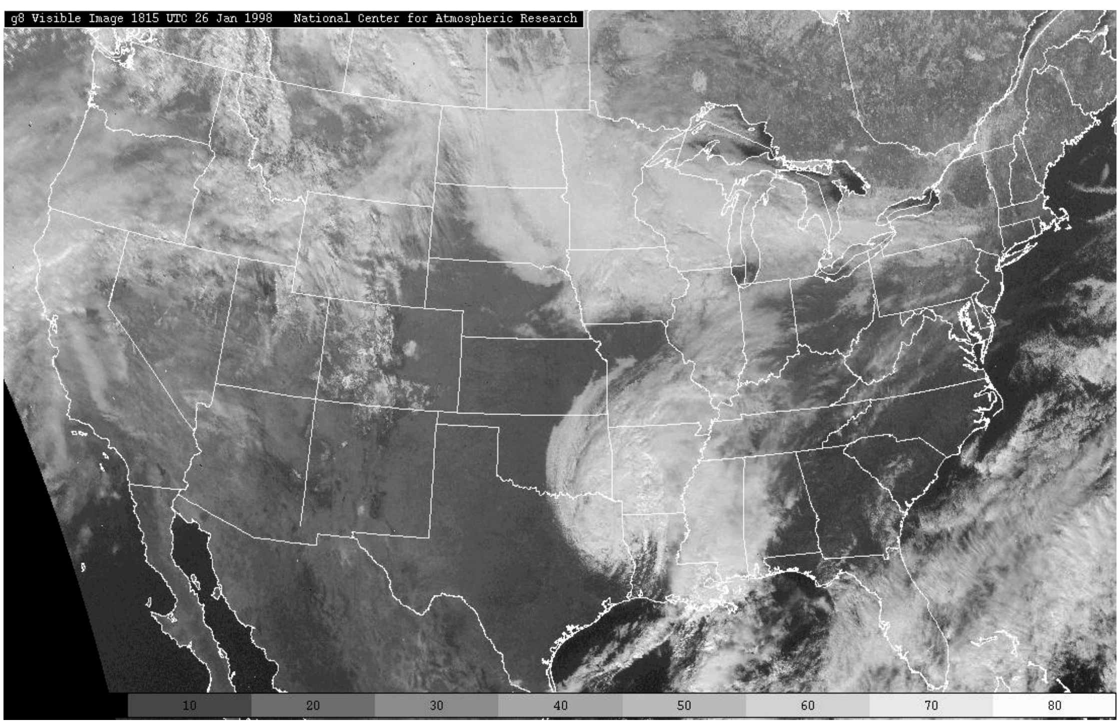
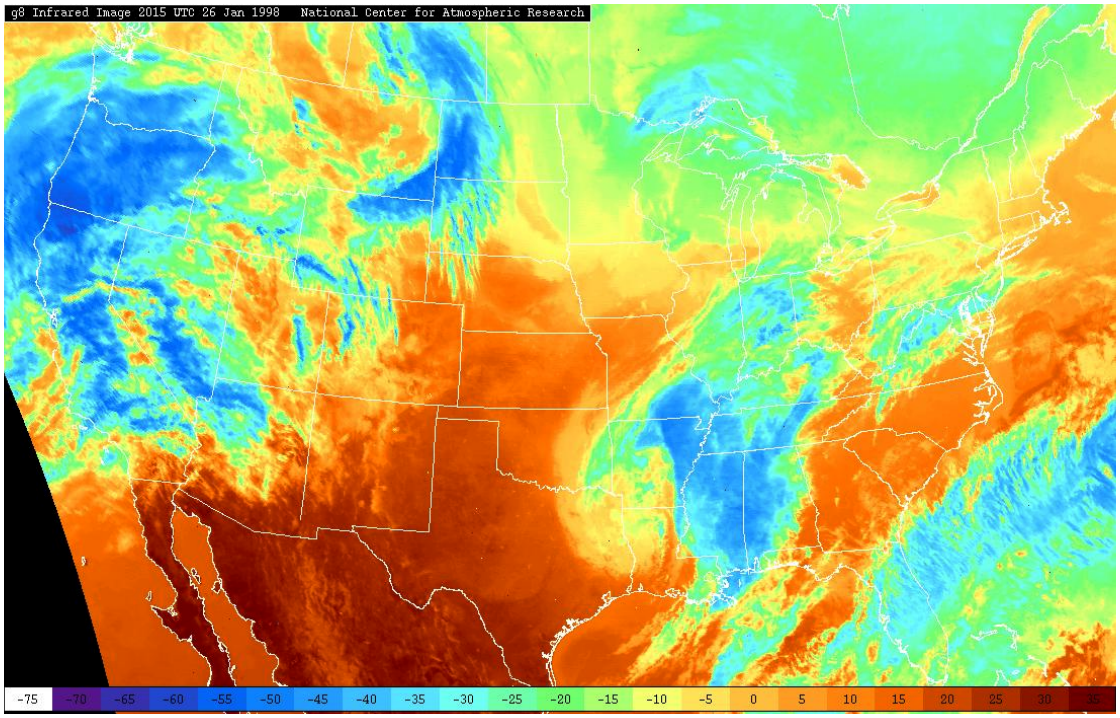


Figure 5 – GOES-8 e) infrared and f) visible satellite images for 980126, 1815 UTC.



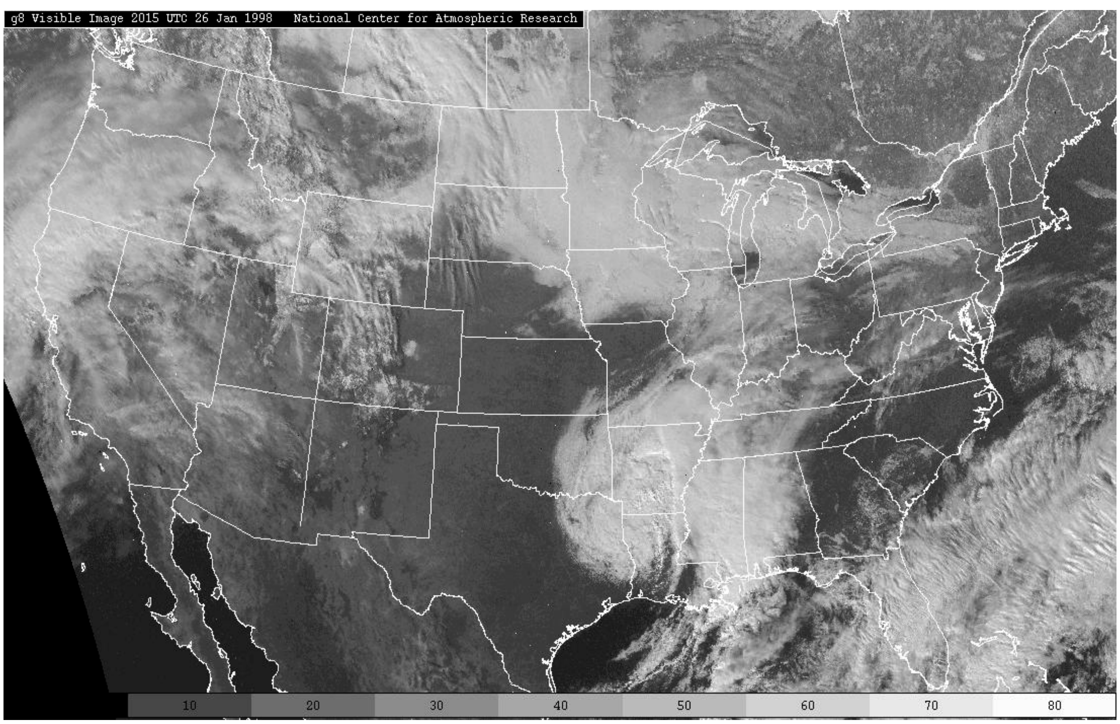
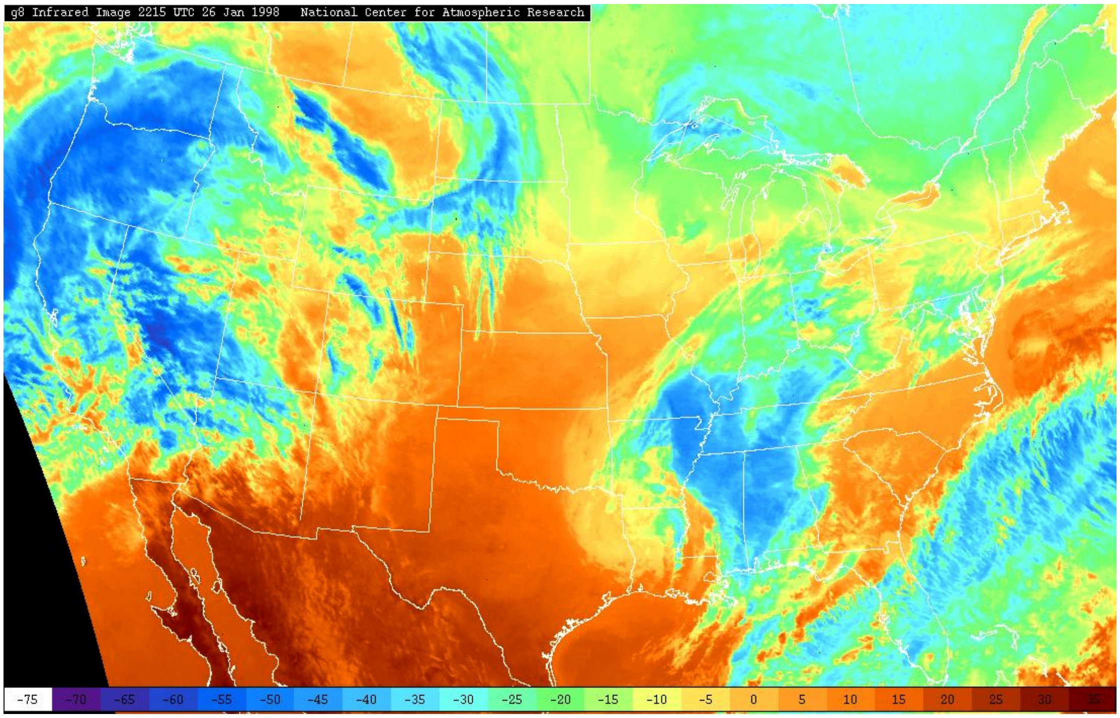


Figure 5 – GOES-8 g) infrared and h) visible satellite images for 980126, 2015 UTC.



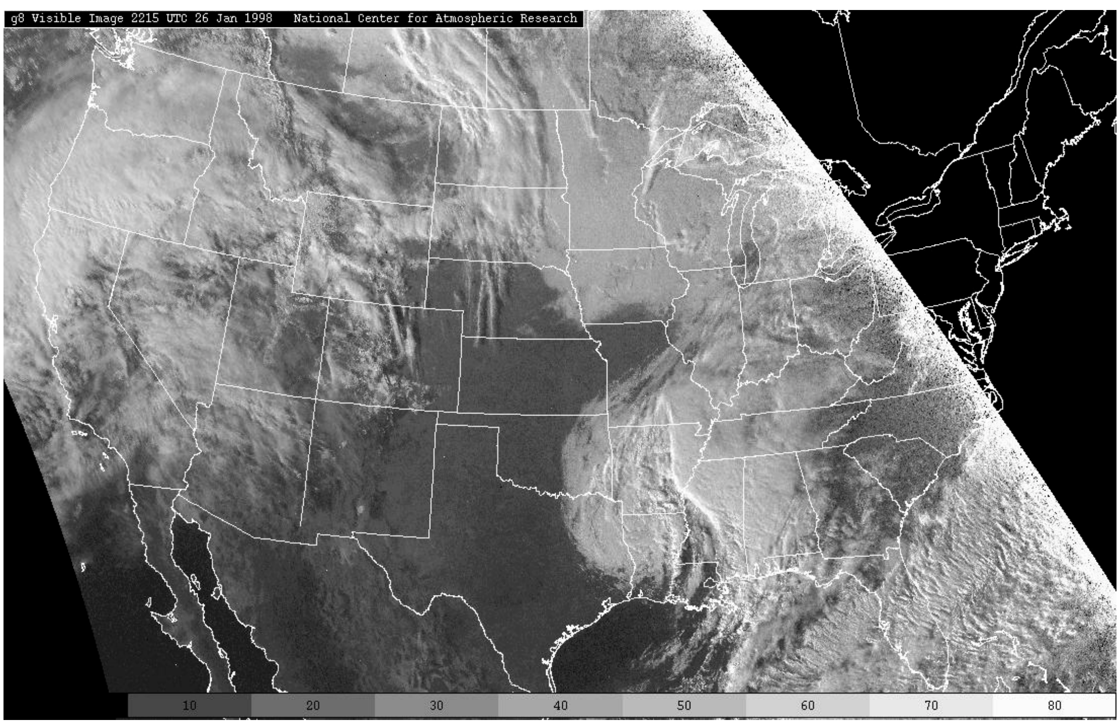
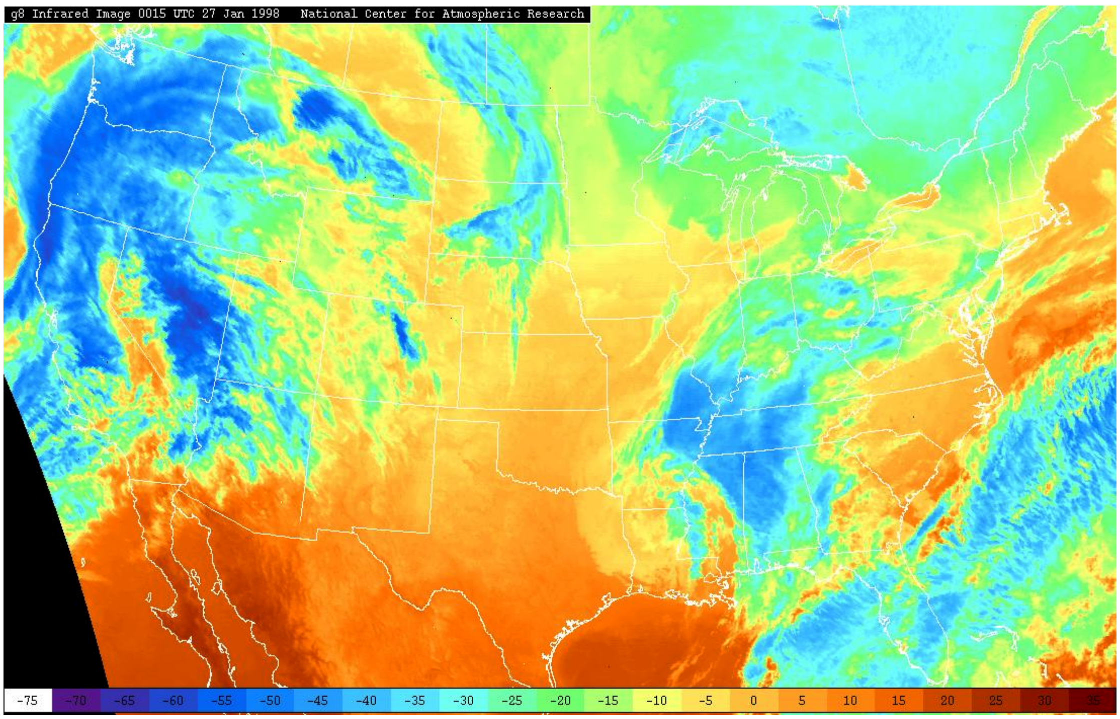


Figure 5 – GOES-8 i) infrared and j) visible satellite images for 980126, 2215 UTC.



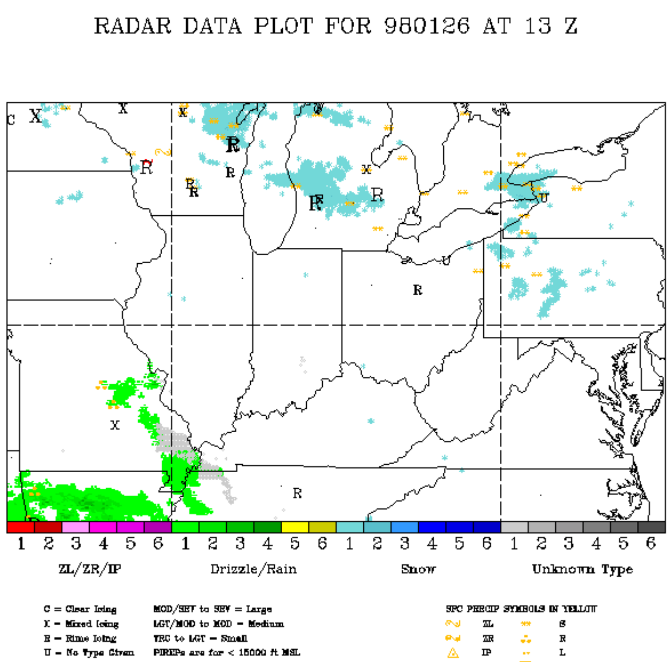
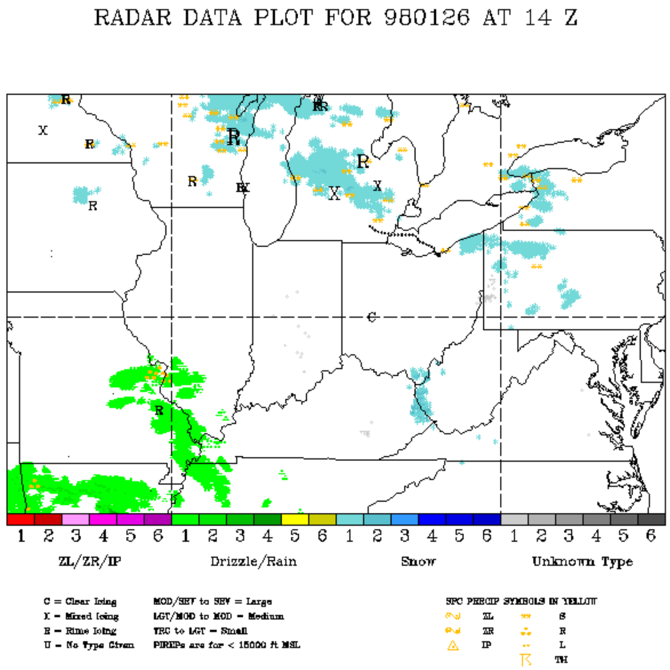


Figure 5 – GOES-8 k) infrared satellite image for 980127, 0015 UTC.
Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for a) 980126, 1300 UTC.



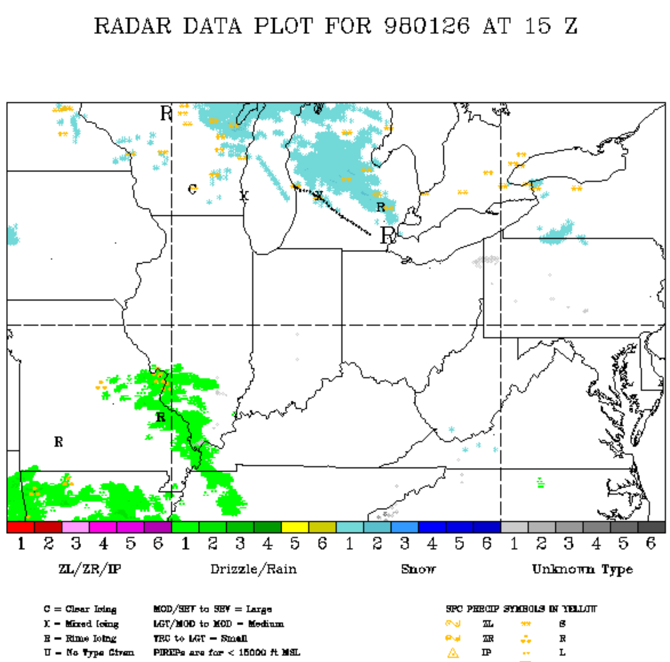
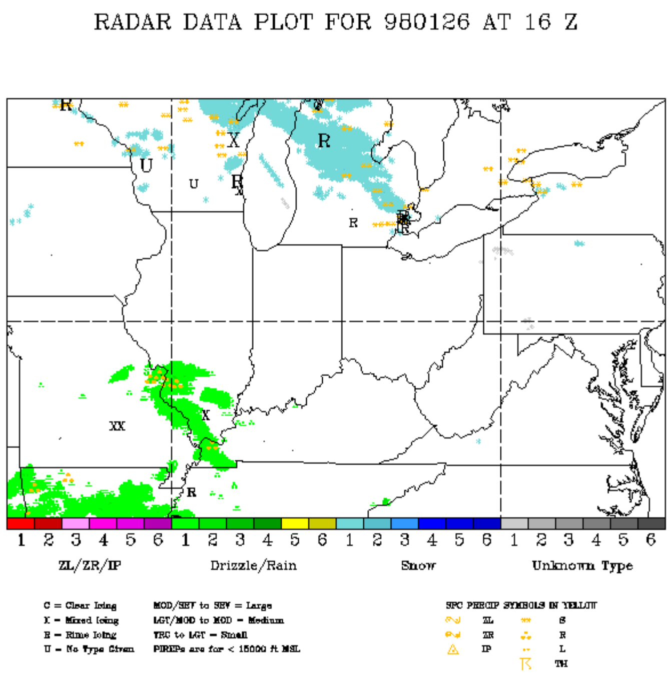


Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980126, b) 1400 and c) 1500 UTC.



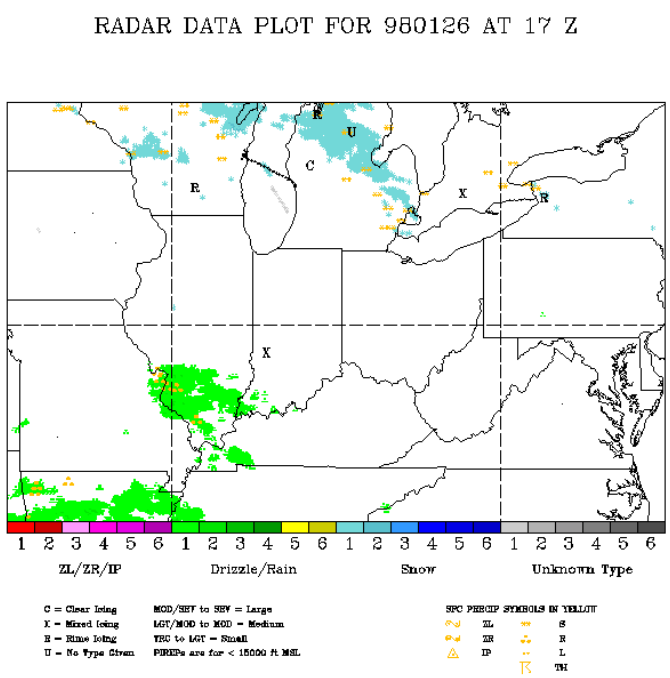
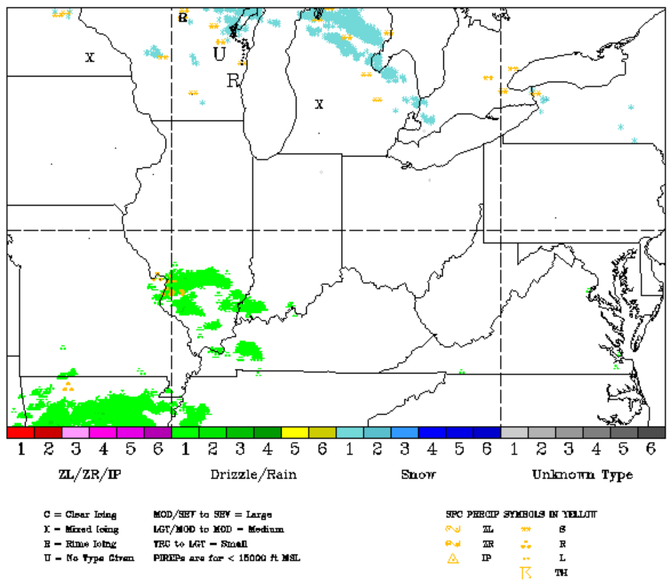


Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980126, d) 1600 and e) 1700 UTC.

RADAR DATA PLOT FOR 980126 AT 18 Z



RADAR DATA PLOT FOR 980126 AT 19 Z

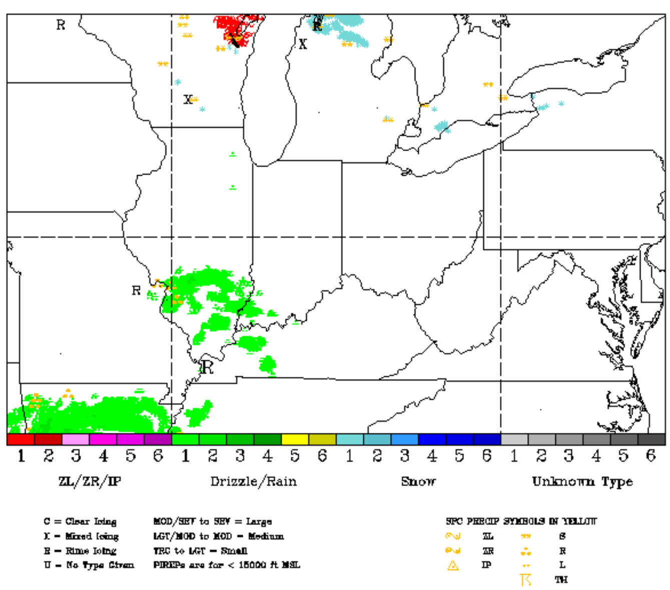
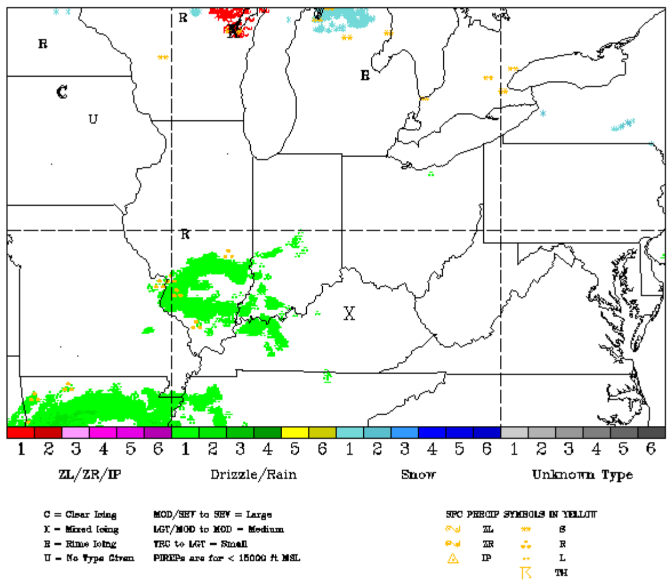


Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980126, f) 1800 and g) 1900 UTC.

RADAR DATA PLOT FOR 980126 AT 20 Z



RADAR DATA PLOT FOR 980126 AT 21 Z

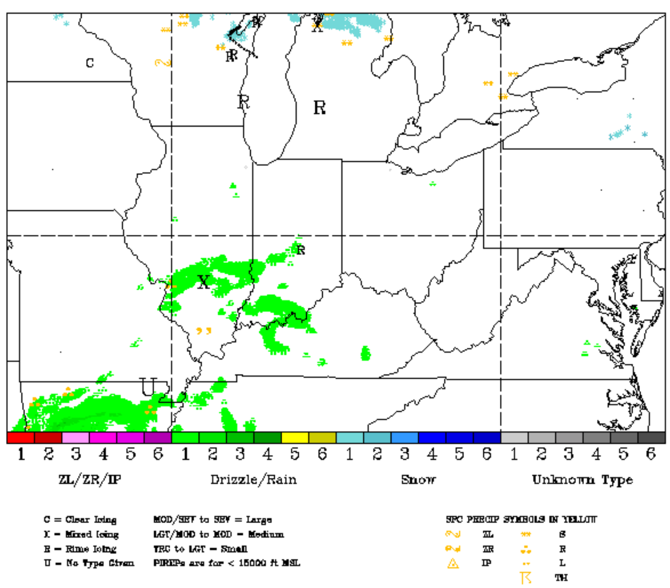
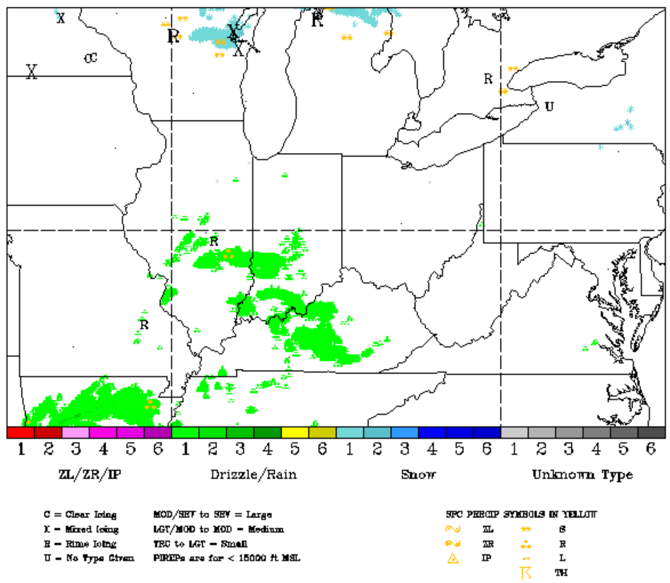


Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980126, h) 2000 and i) 2100 UTC.

RADAR DATA PLOT FOR 980126 AT 22 Z



RADAR DATA PLOT FOR 980126 AT 23 Z

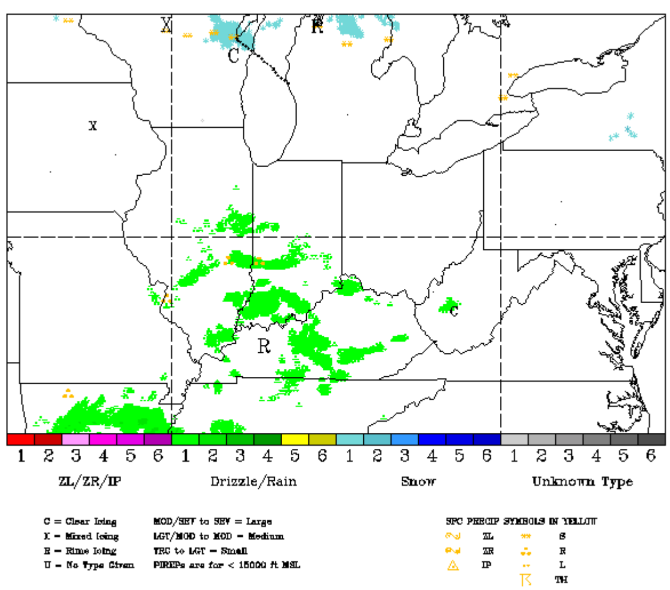


Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980126, j) 2200 and k) 2300 UTC.

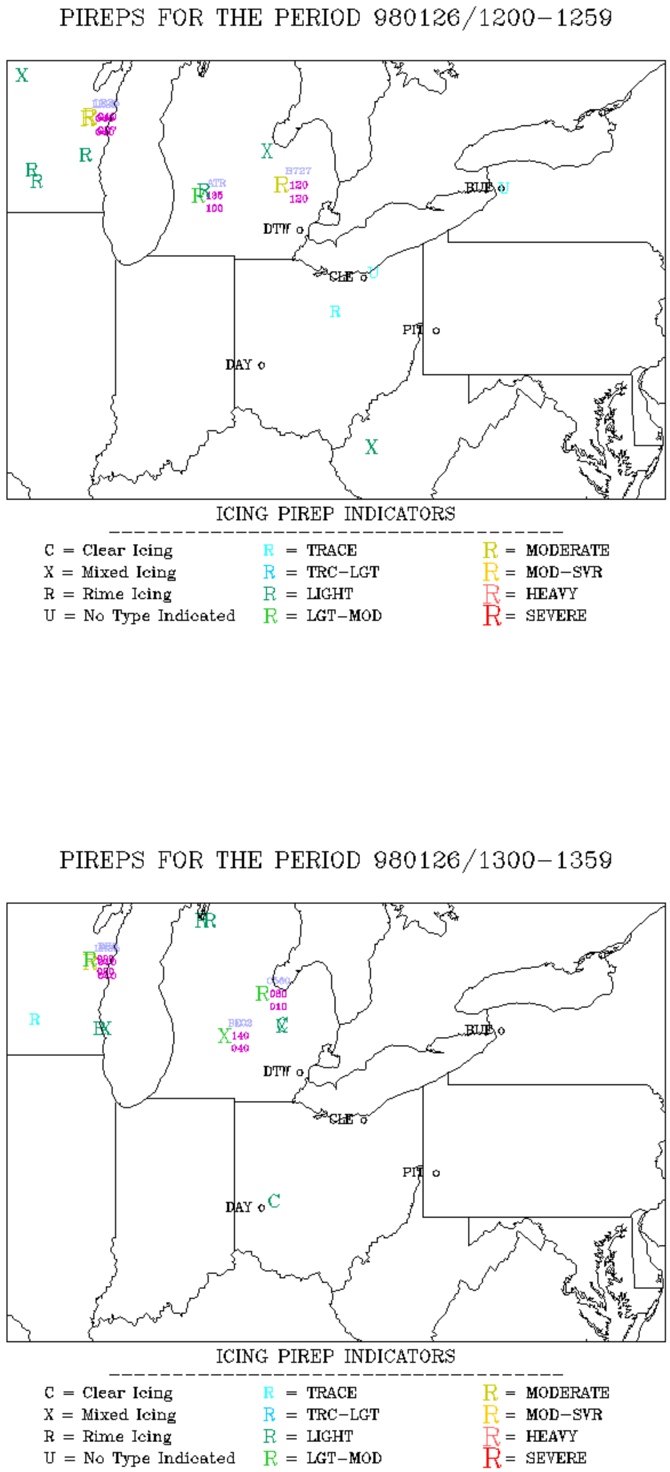
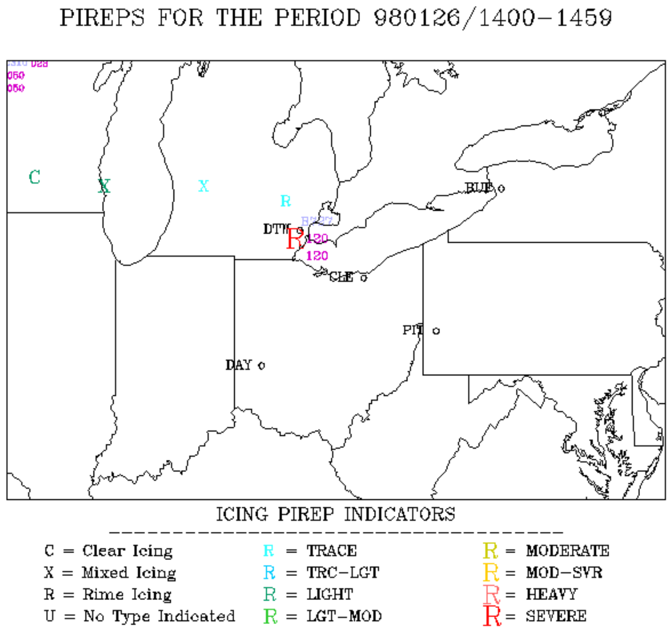


Figure 7 – Pilot reports of icing for 980126, a) 1200-1259 and b) 1300-1359 UTC.



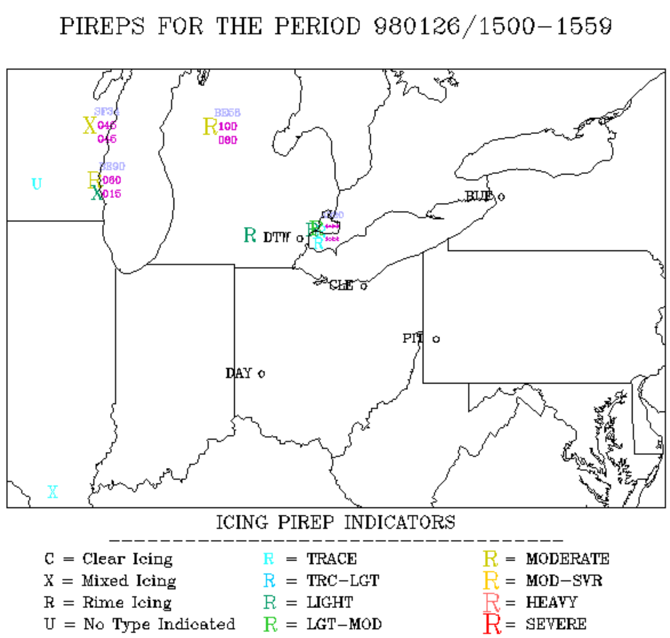
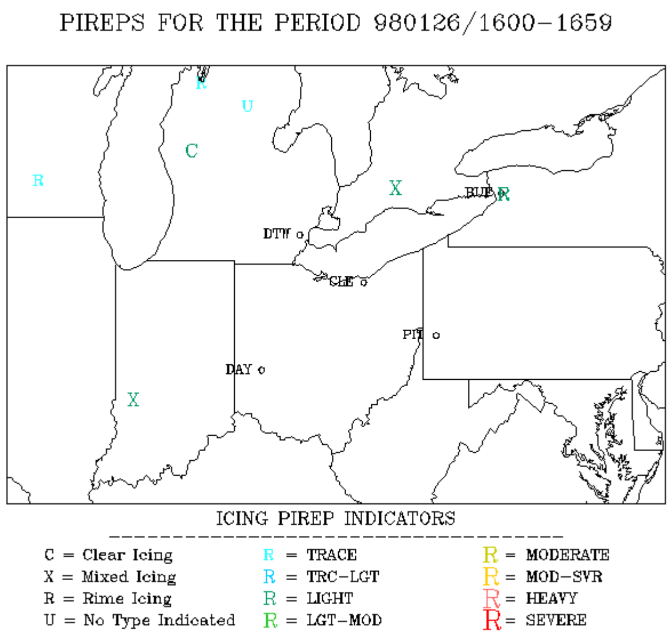


Figure 7 – Pilot reports of icing for 980126, c) 1400-1459 and d) 1500-1559 UTC.



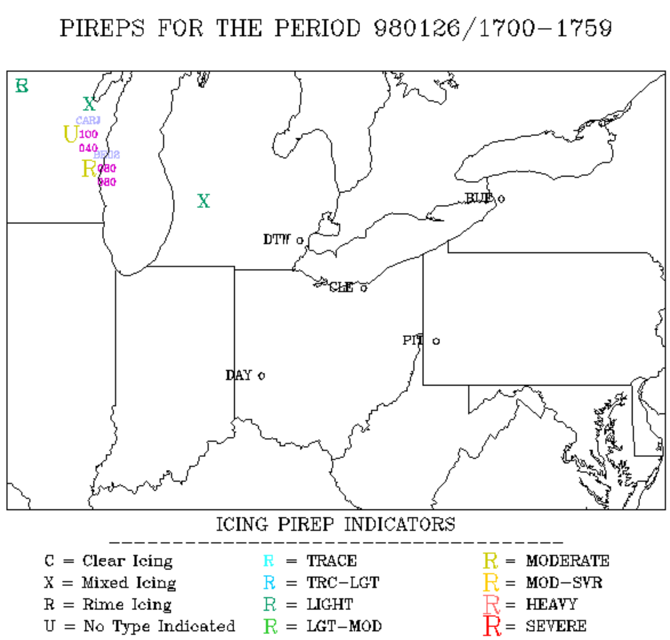
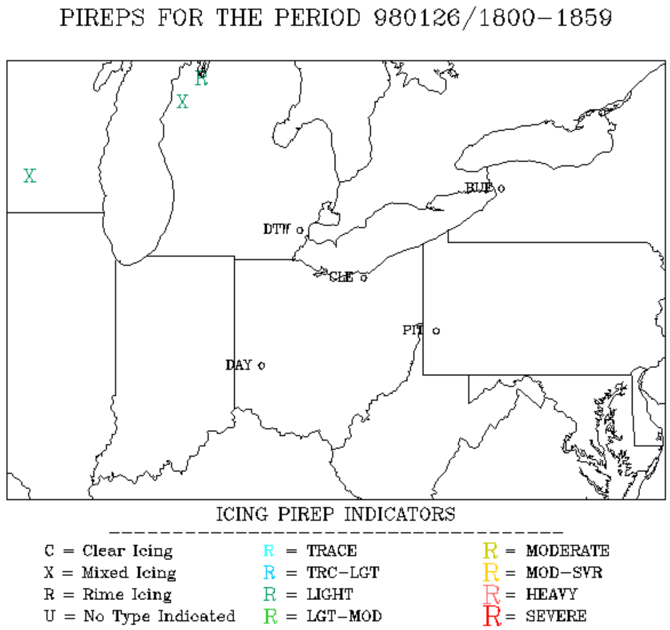


Figure 7 – Pilot reports of icing for 980126, e) 1600-1659 and f) 1700-1759 UTC.



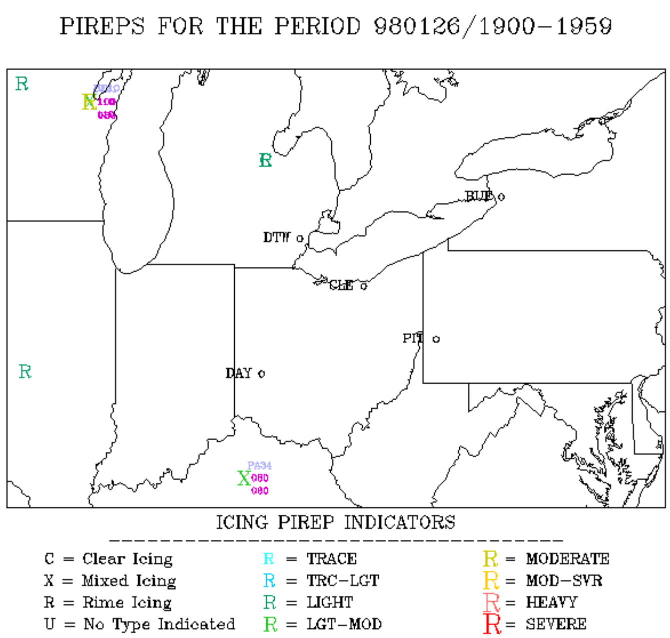


Figure 7 – Pilot reports of icing for 980126, g) 1800-1859 and h) 1900-1959 UTC.

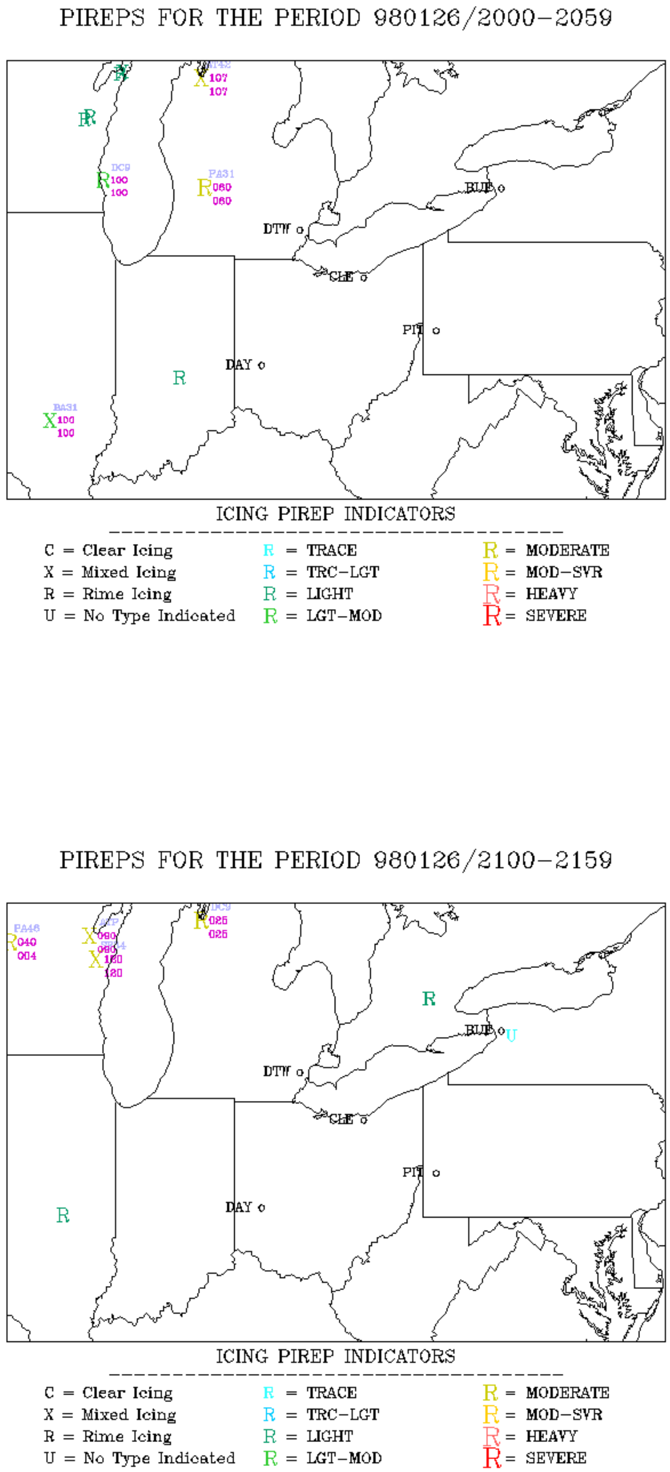
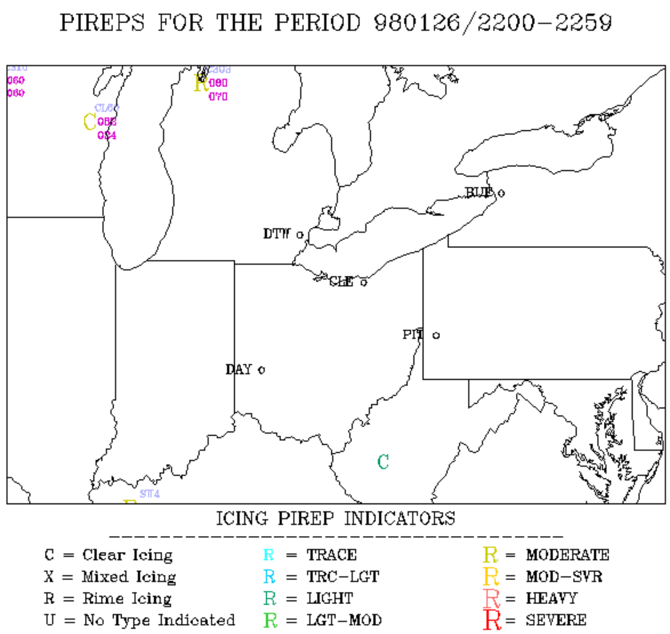


Figure 7 – Pilot reports of icing for 980126, i) 2000-2059 and j) 2100-2159 UTC.



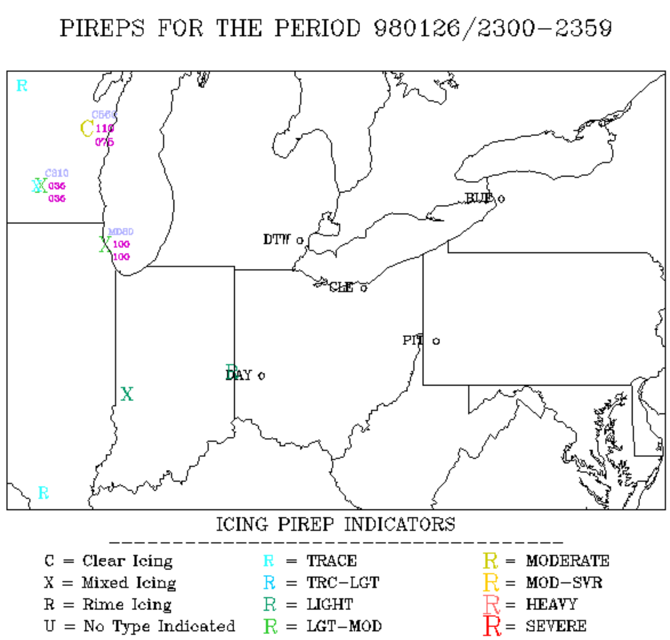


Figure 7 – Pilot reports of icing for 980126, k) 2200-2259 and l) 2300-2359 UTC.

January 27, 1998

Flight #1—Over Selfridge AFB and southern Lake Huron from 1448 to 1644 UTC.
Flight #2—Over Selfridge AFB and Lake Erie from 1746 to 1830 UTC.

Brief overview

Two flights were made into mostly mixed phase clouds over eastern Michigan and southern Lake Huron on this day. During the first flight, mostly snow and essentially no liquid water was encountered over Lake Erie, southeastern Ontario, and near Selfridge Air Force Base. Light amounts of liquid water (0-0.2) were observed between Selfridge and Flint, where snow was less prevalent. Near the southwestern shore of Lake Huron, some freezing drizzle (ZL) with temperatures near –5C was observed during two different passes. Over the lake, mixed conditions with only small droplets dominated. Crystal habits were mostly needles and columns, and LWCs were up to 0.3 there. The second flight was essentially a ferry to Cleveland, but more small-droplet and mixed phase clouds were observed from Selfridge to about half way across Lake Erie. Skies were clear over the southern half of the lake.

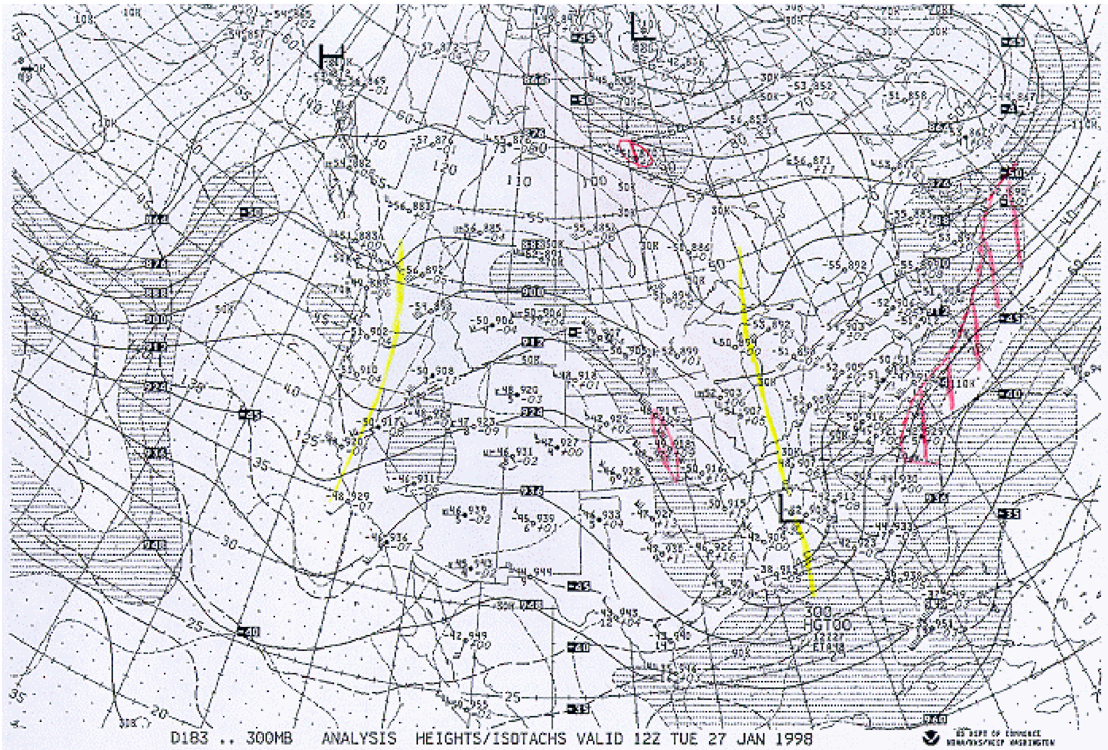
Relevant weather features

At 1200 UTC, a north-south oriented 300 mb trough ran from Lake Superior to the Florida Panhandle (Fig. 1). Southwest flow occurred ahead of the trough, but jet winds in excess of 90 knots were only found along the Atlantic coastline. The 500 mb and 700 mb troughs were roughly co-located with the 300 mb trough, running along the Indiana/Illinois border and through Lake Michigan. At 500 mb, a weak, closed low was centered over southwestern Alabama. Moist air covered areas to the east of Indianapolis and Saginaw, while dry air was found just to the southwest. The southern low was weaker at 700 mb, and a secondary trough ran eastward from the low to the Georgia coast. Warm advection and moist air were prevalent across the forecast area at this level. At 850 mb, the southern low was stronger. Both it, and the main trough, were further to the east, with the trough running the across central Ohio and southeastern Michigan. Fairly dry air covered much of Ohio, but moist conditions were in place across Michigan and Indiana. Warm advection was found ahead of the trough, in northeastern Ohio and over Lake Huron.

At the surface (Fig. 2), a 1007 mb low was located over northern Florida and eastern Georgia, while a 1037 mb high was centered over western Maine. Weak southeasterly flow resulted from the more slack pressure gradient over Ohio and Michigan. The southeasterly flow brought warm air up to meet some rather cold air over Ontario, causing a weak warm front to form across Lakes Superior, Huron, and Erie. Intermittent light snow fell along the frontal zone in areas of cooler cloud tops (Fig. 3). Overcast conditions persisted elsewhere. Dry air approaching from the southwest caused breaks in the cloud cover to move into Indiana and Ohio later in the day. The warm front and light snow drifted slowly northward as the surface low lumbered up the East Coast and the high edged eastward across Maine. The Twin Otter sampled the snowy area, its southwestern edge, and the clouds that trailed it (Fig. 4).

Soundings taken at Detroit and Alpena MI (Fig. 5) showed the warm front at about 950 and 900 mb, respectively, and the shallow wedge of cold, arctic air below the front. Warm advection was clearly evident in the veering winds through the warm frontal zone. Deep saturated conditions were present at Detroit (CTT < -20C), while pockets of dry air and cloud were present above a solid lower cloud deck (CTT = -13C) at Alpena. Snow was falling at both locations, but ended by 1800 UTC.

Pilot reports of moderate and lighter severity (Fig. 6) were primarily made in the trailing clouds over Wisconsin, Michigan, Indiana, and Ohio. Icing altitudes were between 7000' and 10,000' to the southwest, and between 10,000' and 13,000' to the northeast of Detroit, respectively. Lower altitude PIREPs (below 8000') were observed within warmer, shallower clouds over eastern Wisconsin.



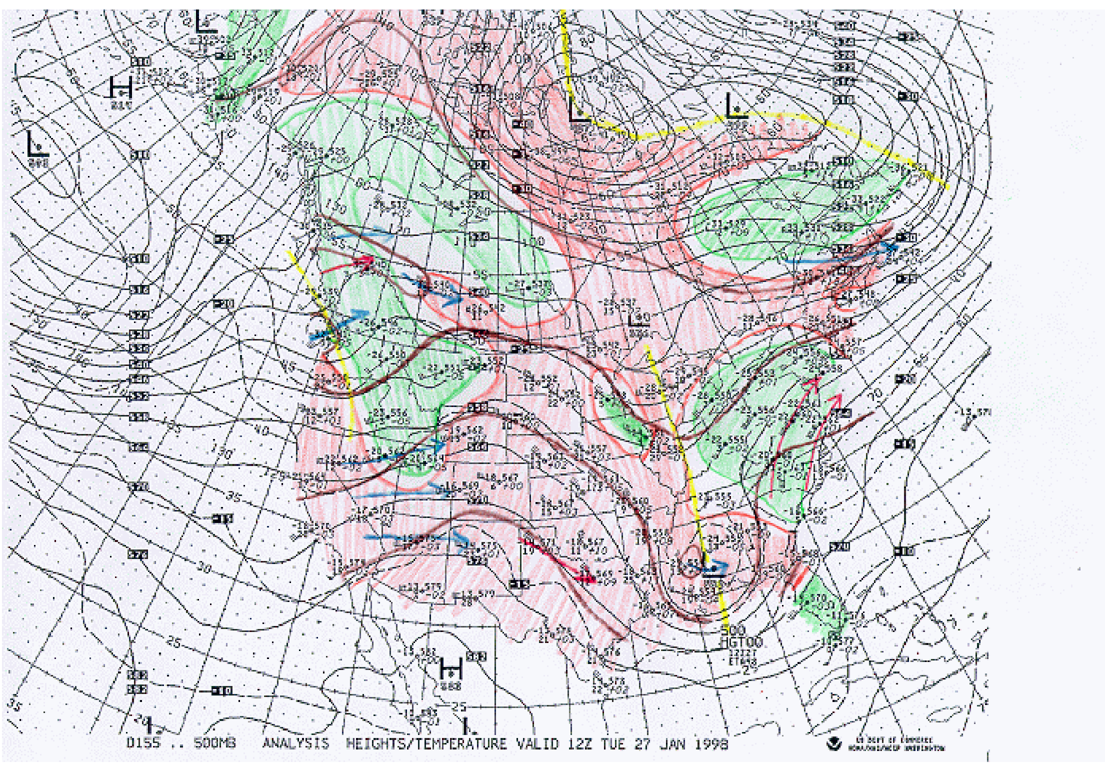
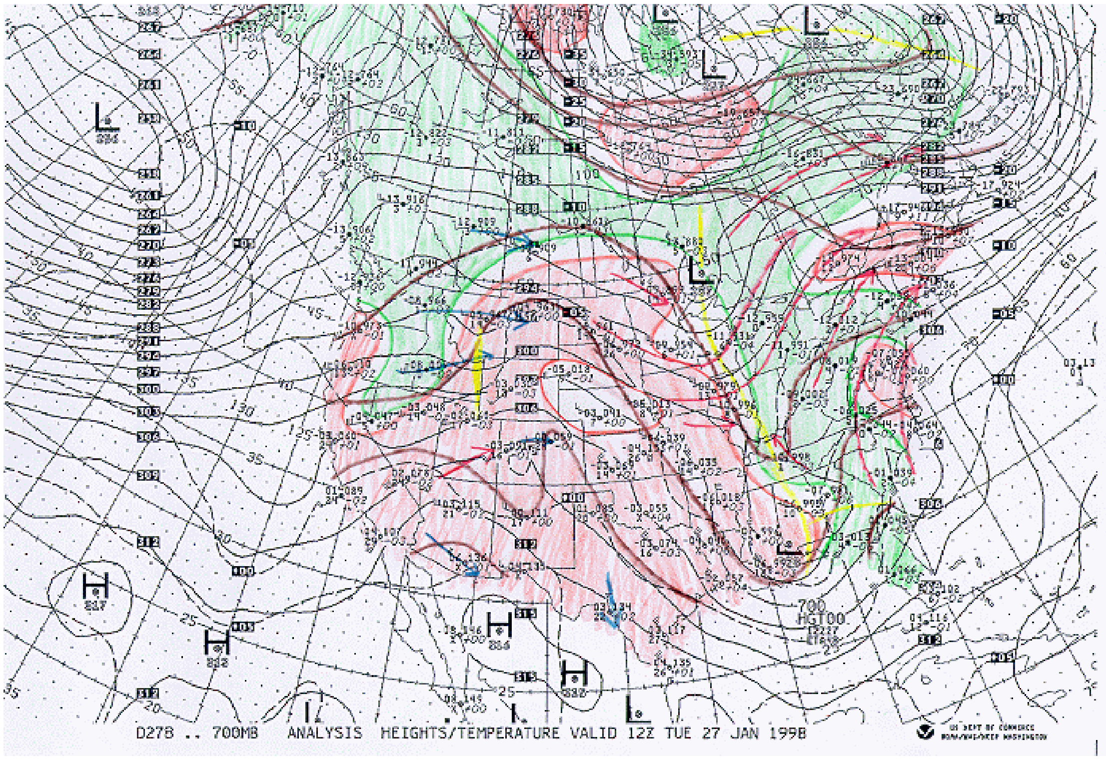


Figure 1 – Upper-air charts for 980127, 1200 UTC at a) 300 and b) 500 mb.



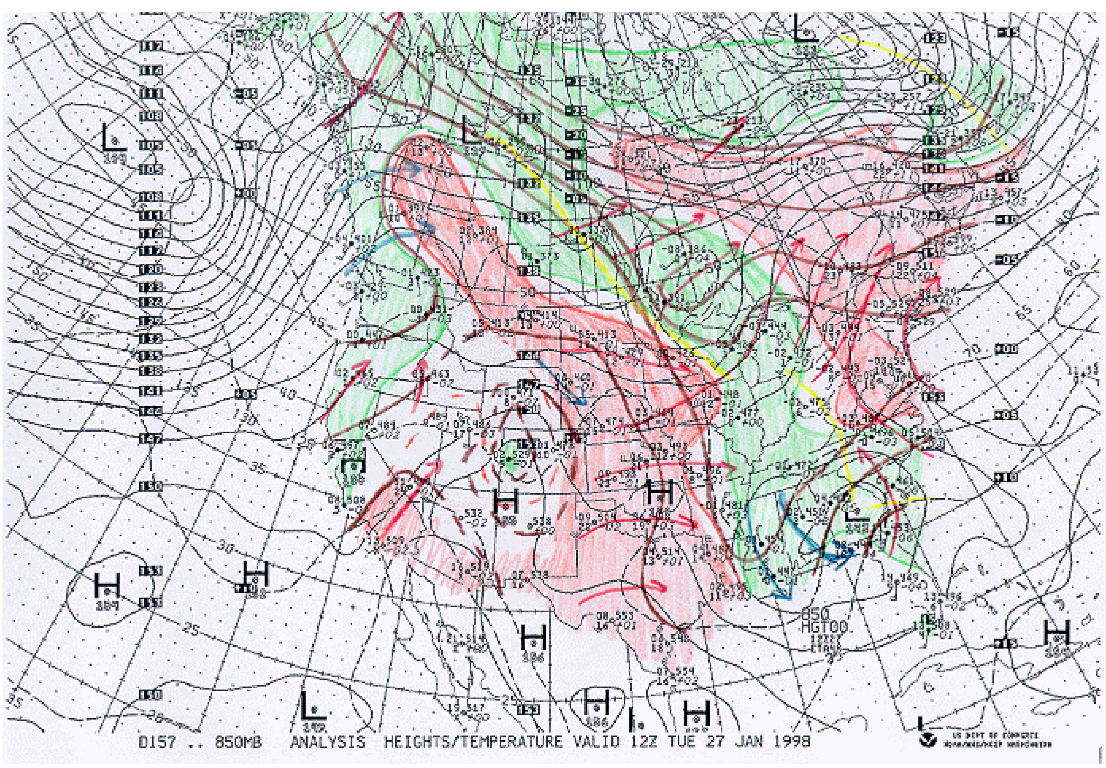


Figure 1 – Upper-air charts for 980127, 1200 UTC at c) 700 and d) 850 mb.

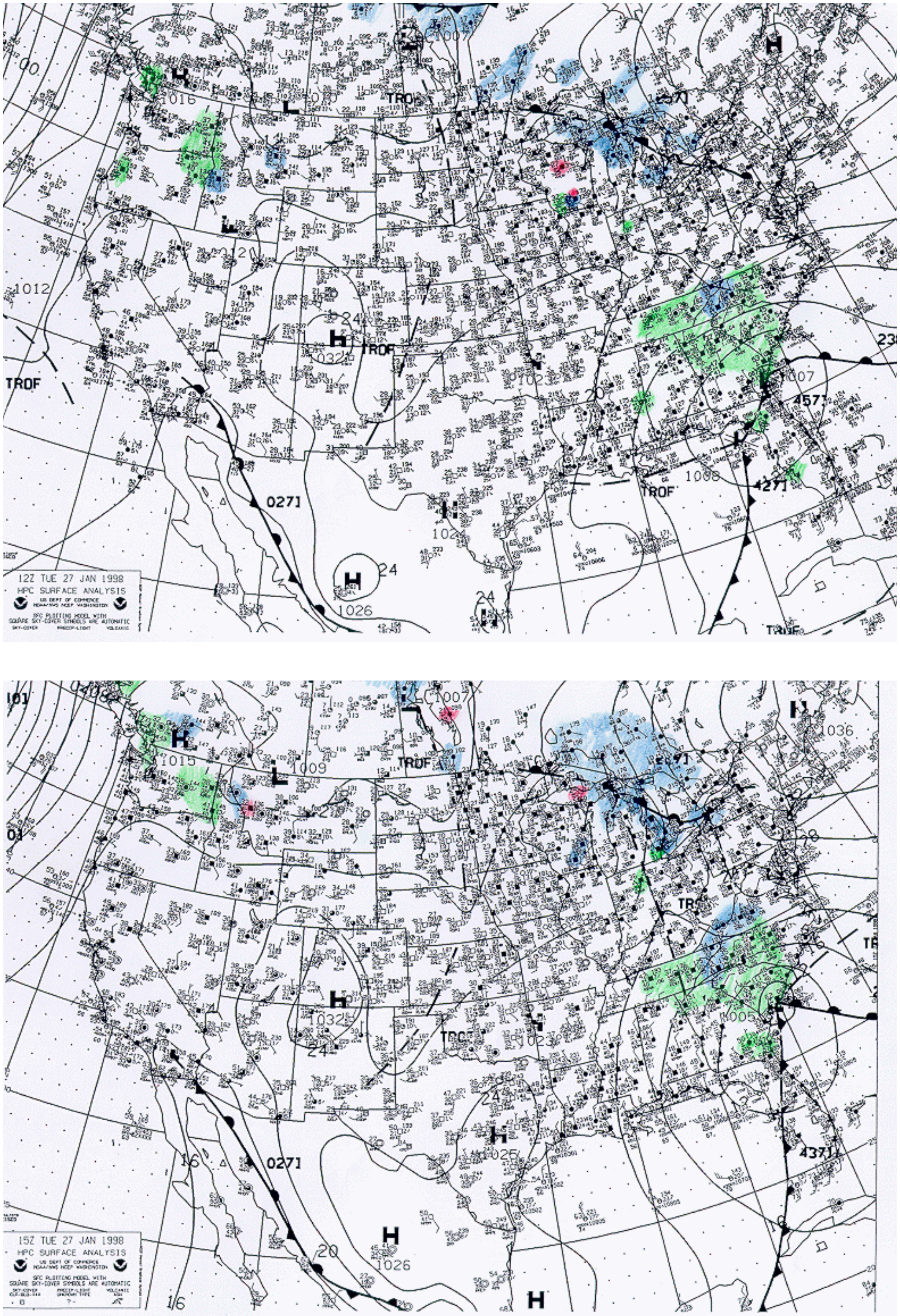
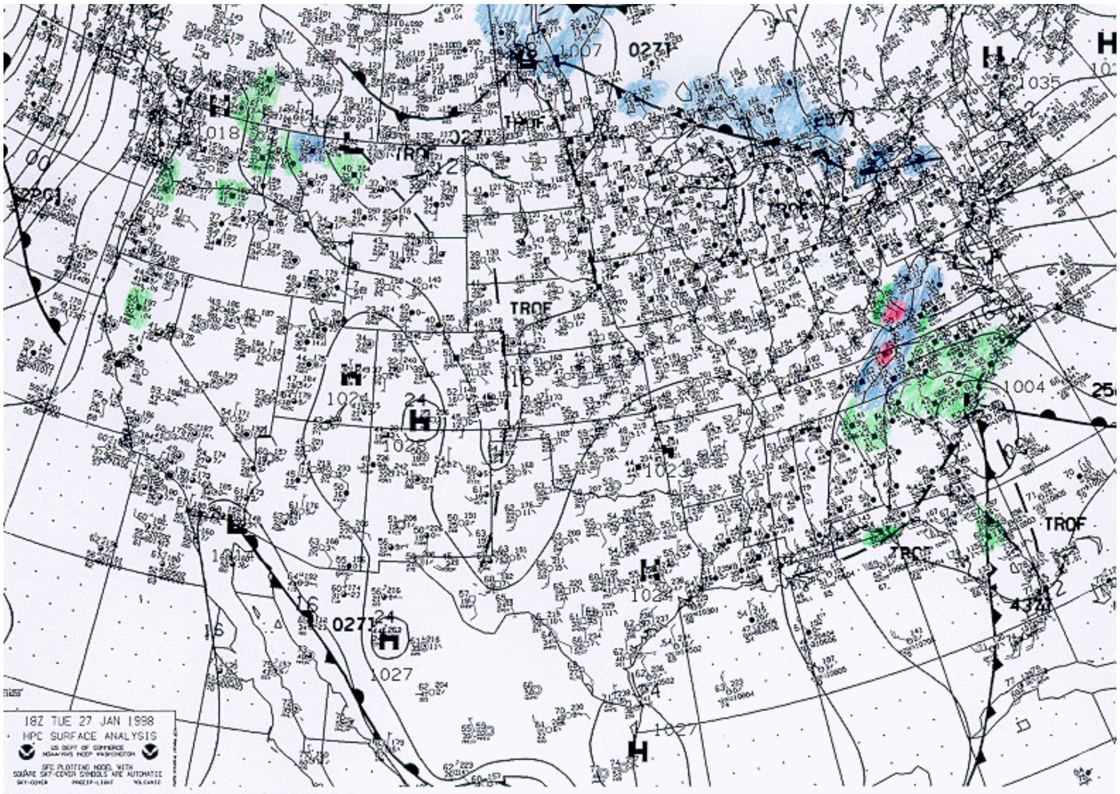


Figure 2 – Surface charts for 980127, a) 1200 and b) 1500 UTC.



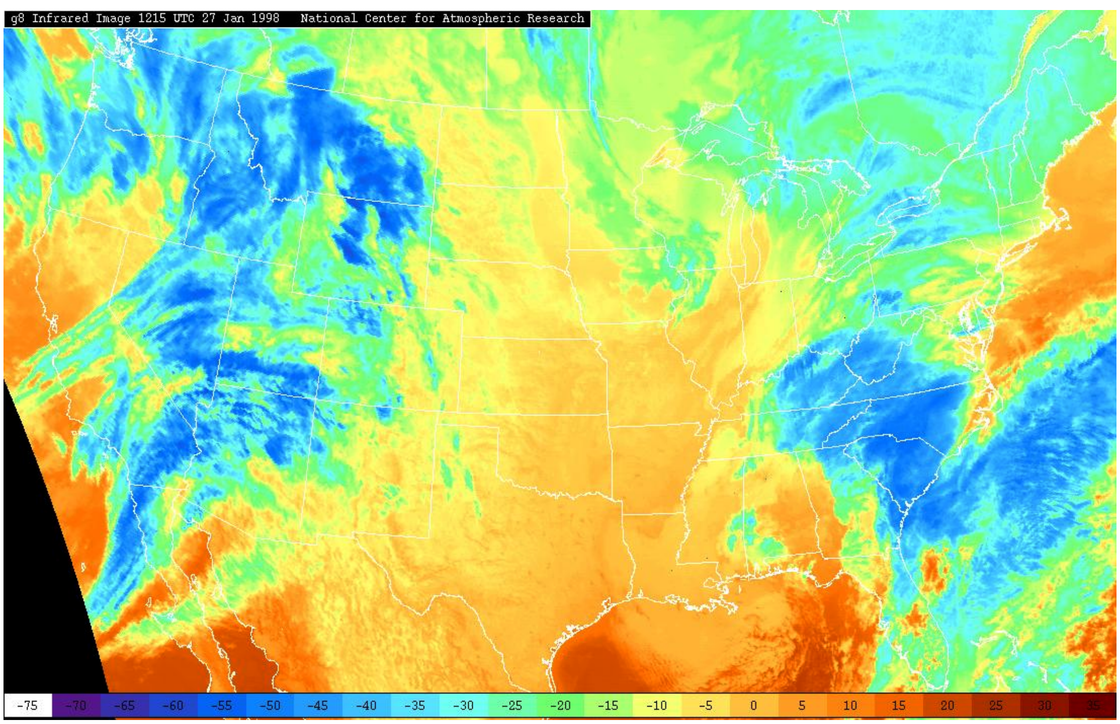
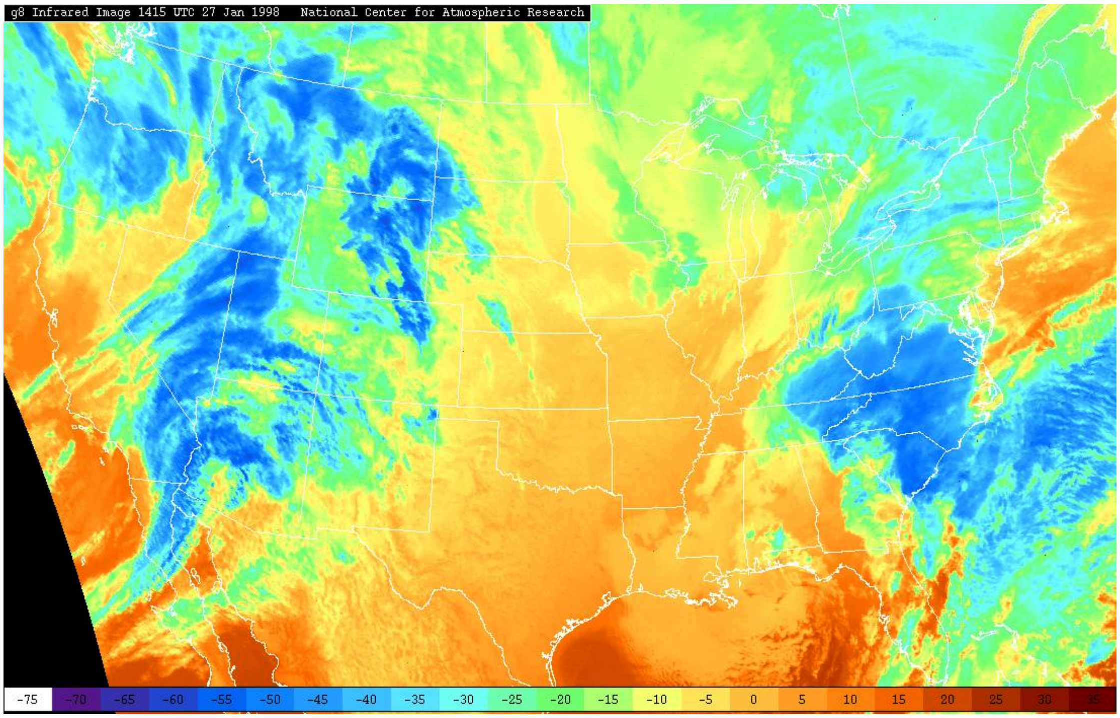


Figure 2 – Surface chart for 980127, c) 1800 UTC.
Figure 3 – GOES-8 a) infrared satellite image for 980127, 1215 UTC.



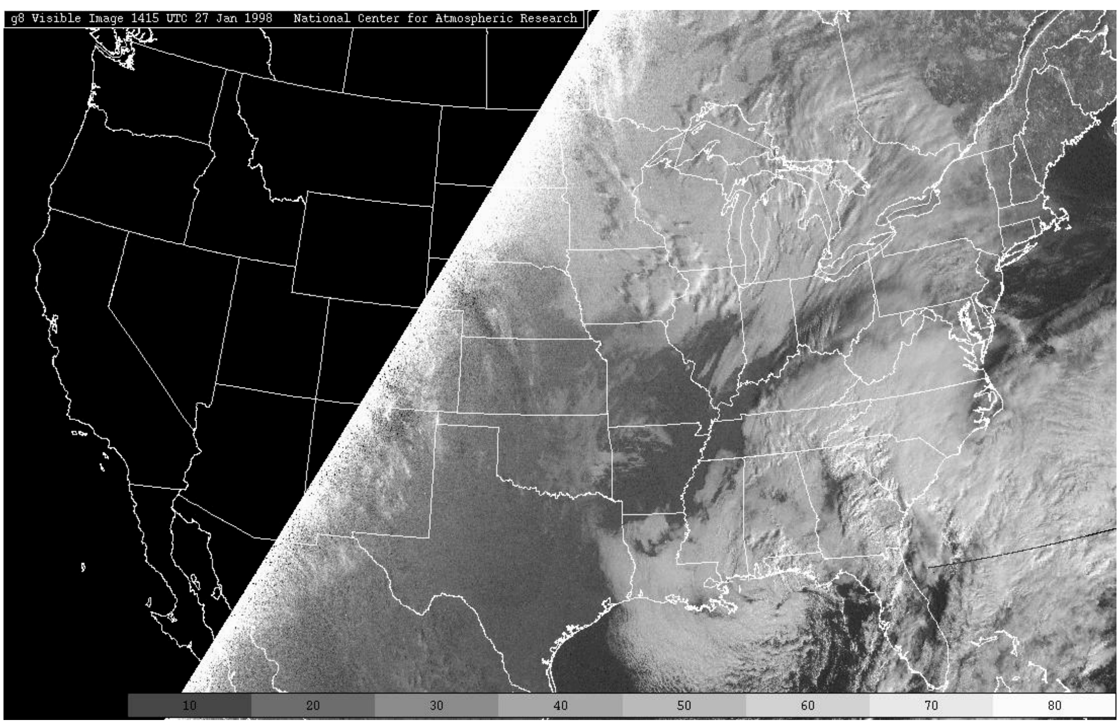
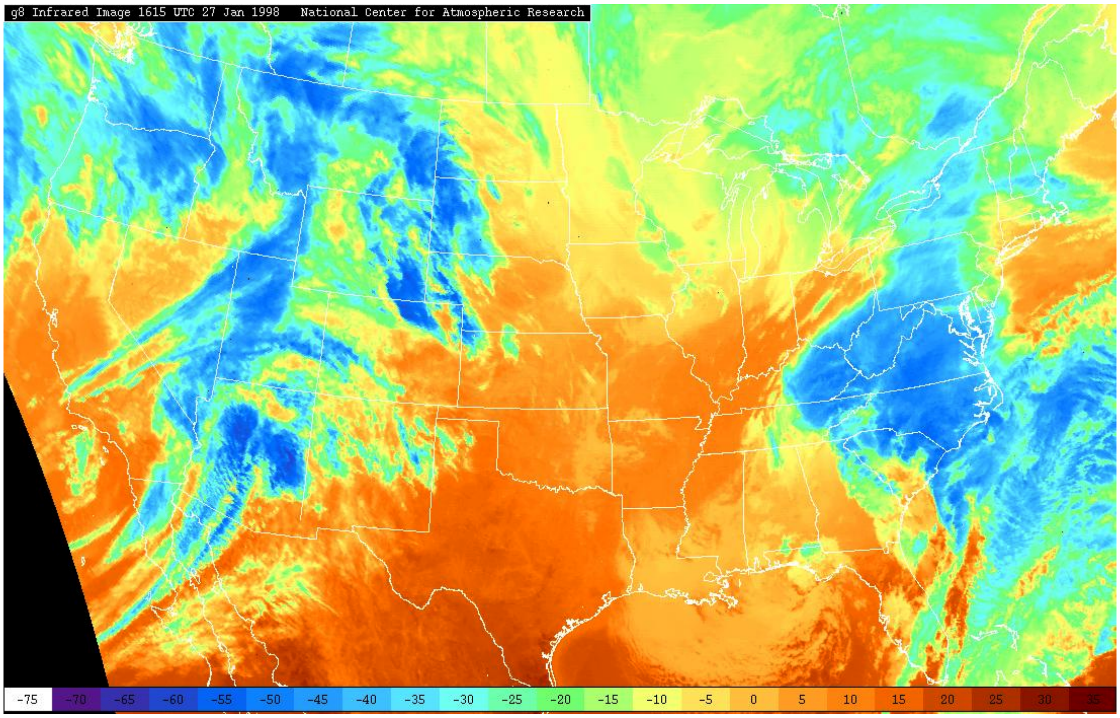


Figure 3 – GOES-8 b) infrared and c) visible satellite images for 980127, 1415 UTC.



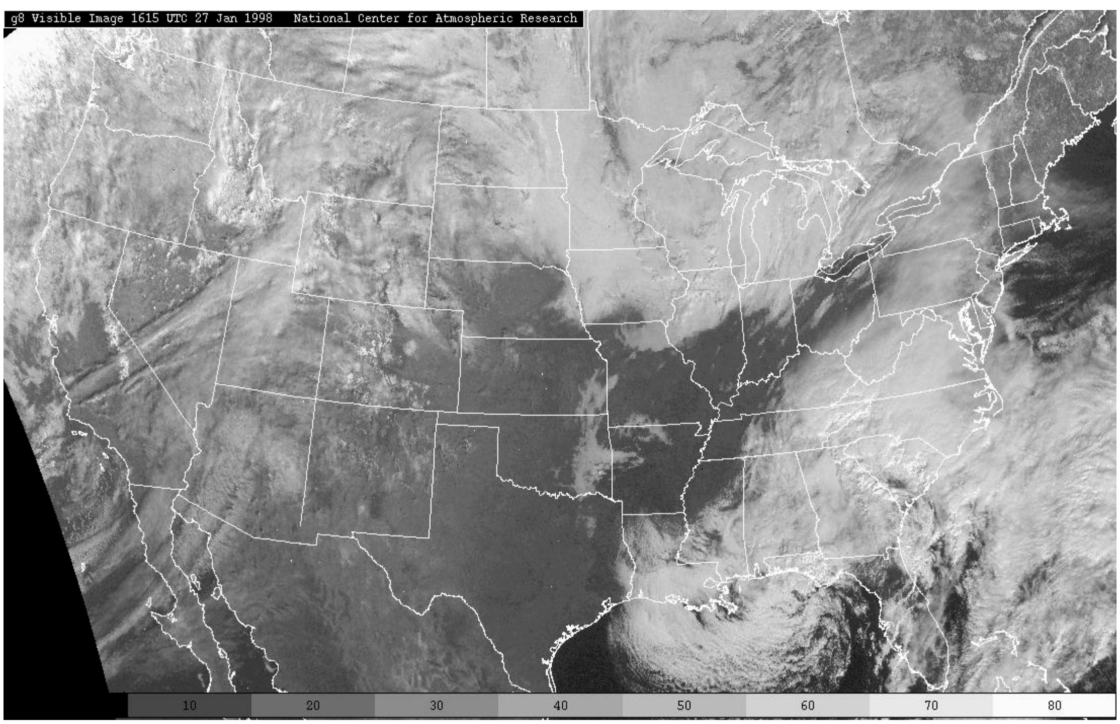
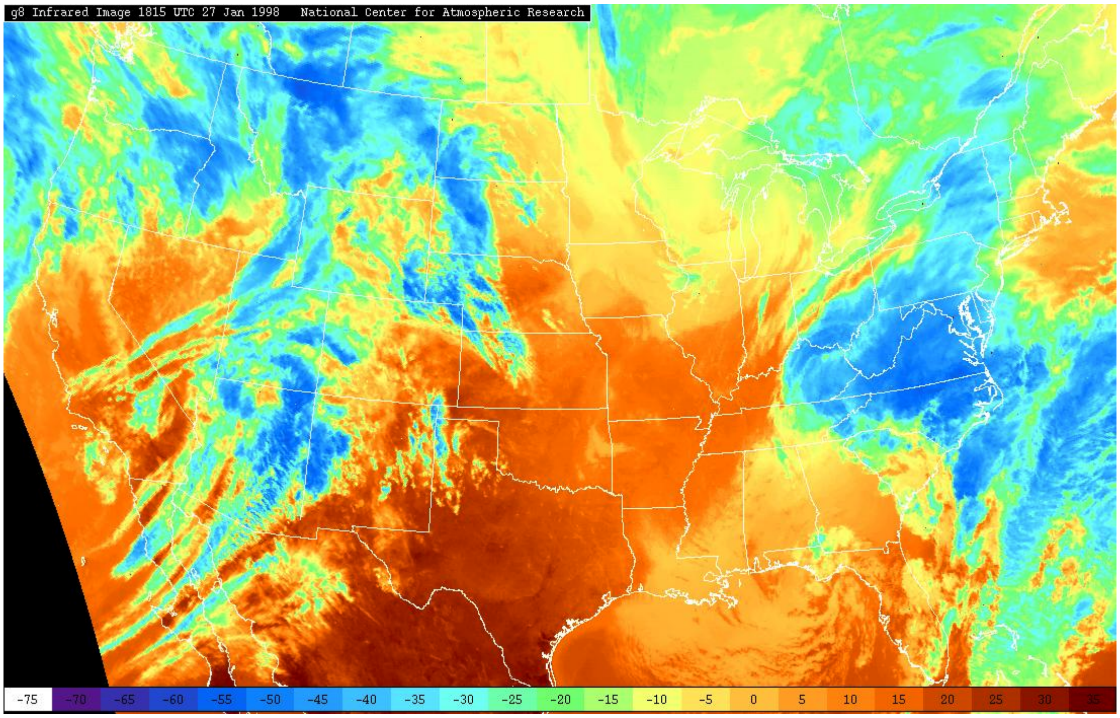


Figure 3 – GOES-8 d) infrared and e) visible satellite images for 980127, 1615 UTC.



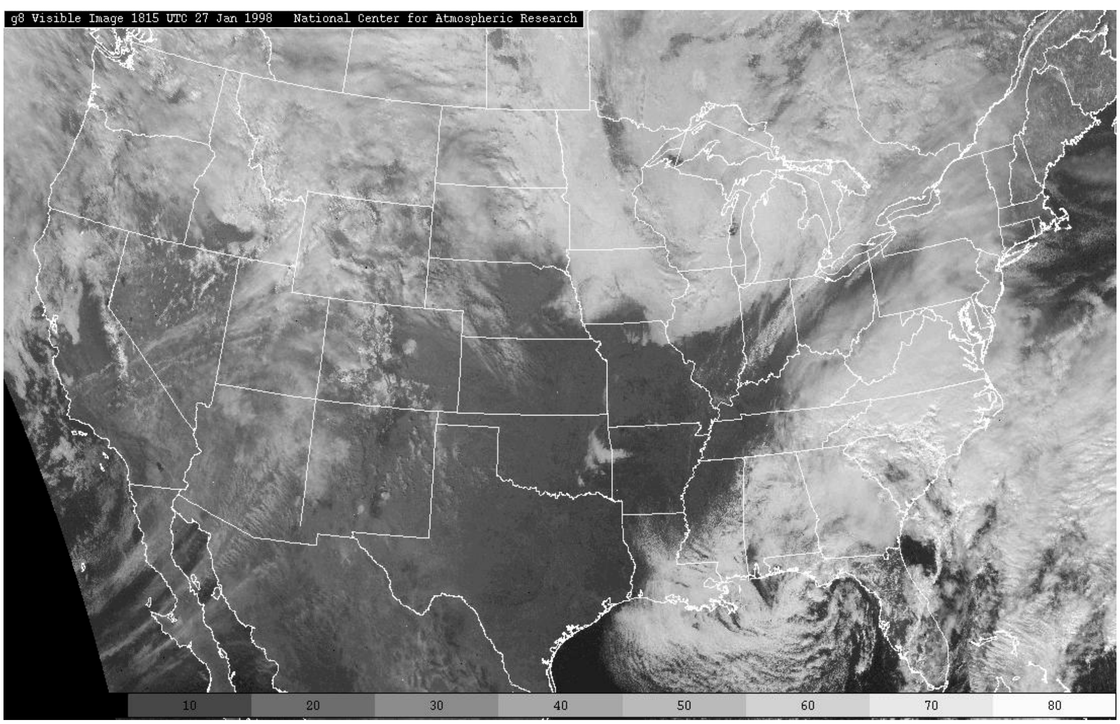
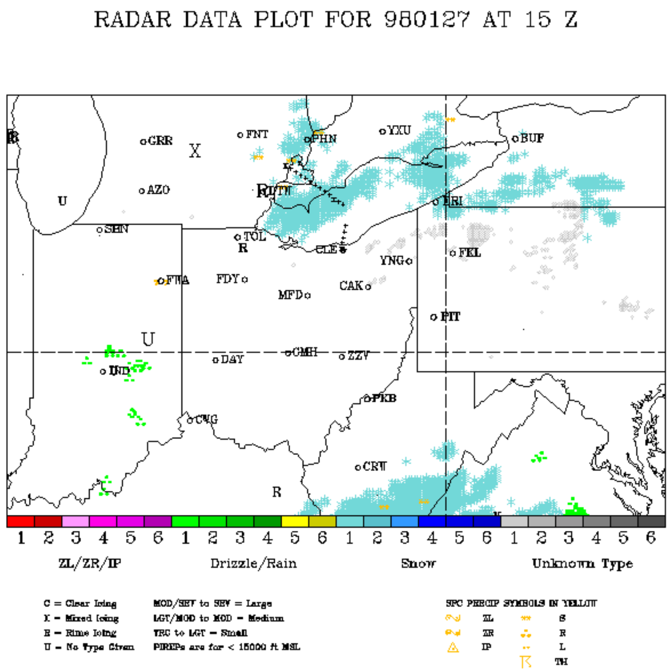


Figure 3 – GOES-8 f) infrared and g) visible satellite images for 980127, 1815 UTC.



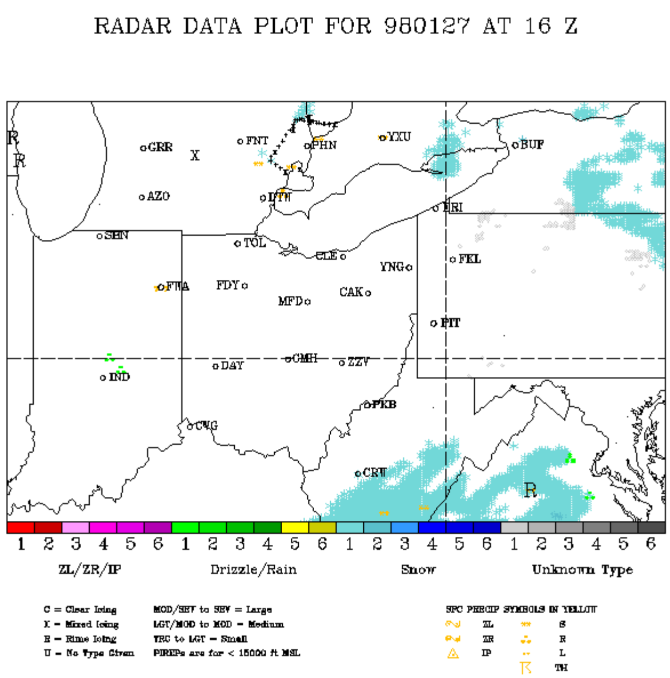
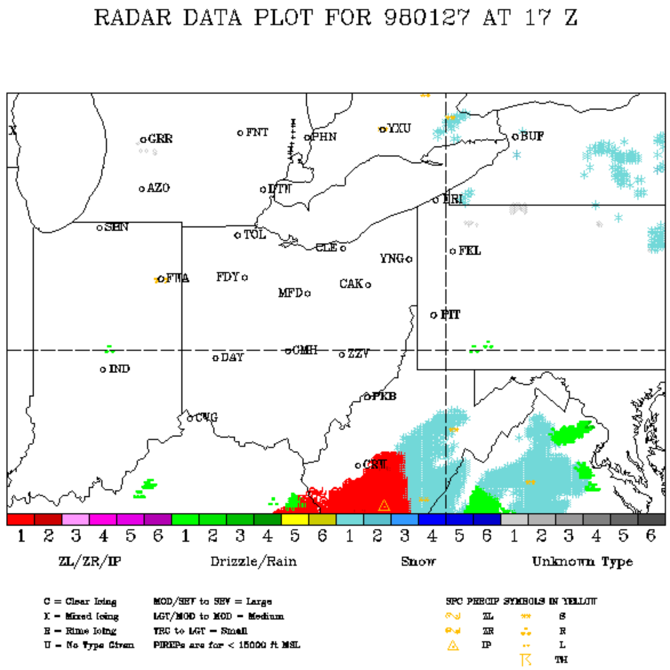


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980127, a) 1500 and b) 1600 UTC.



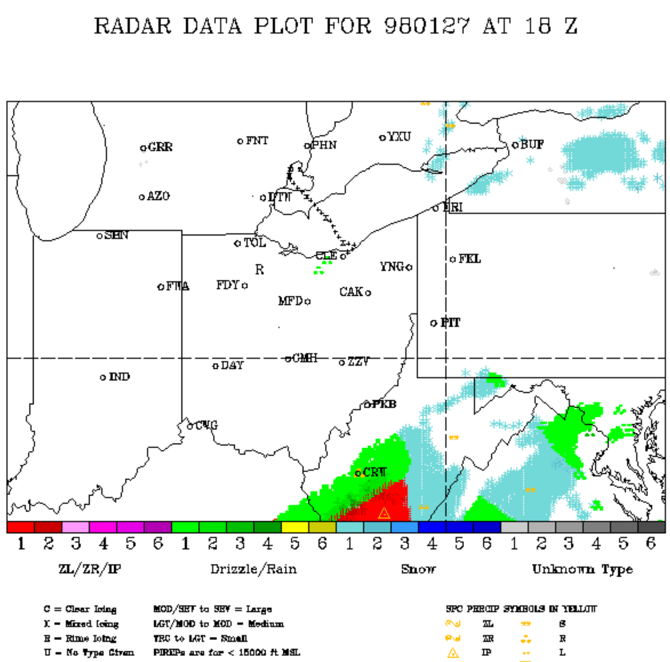


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980127, c) 1700 and d) 1800 UTC.

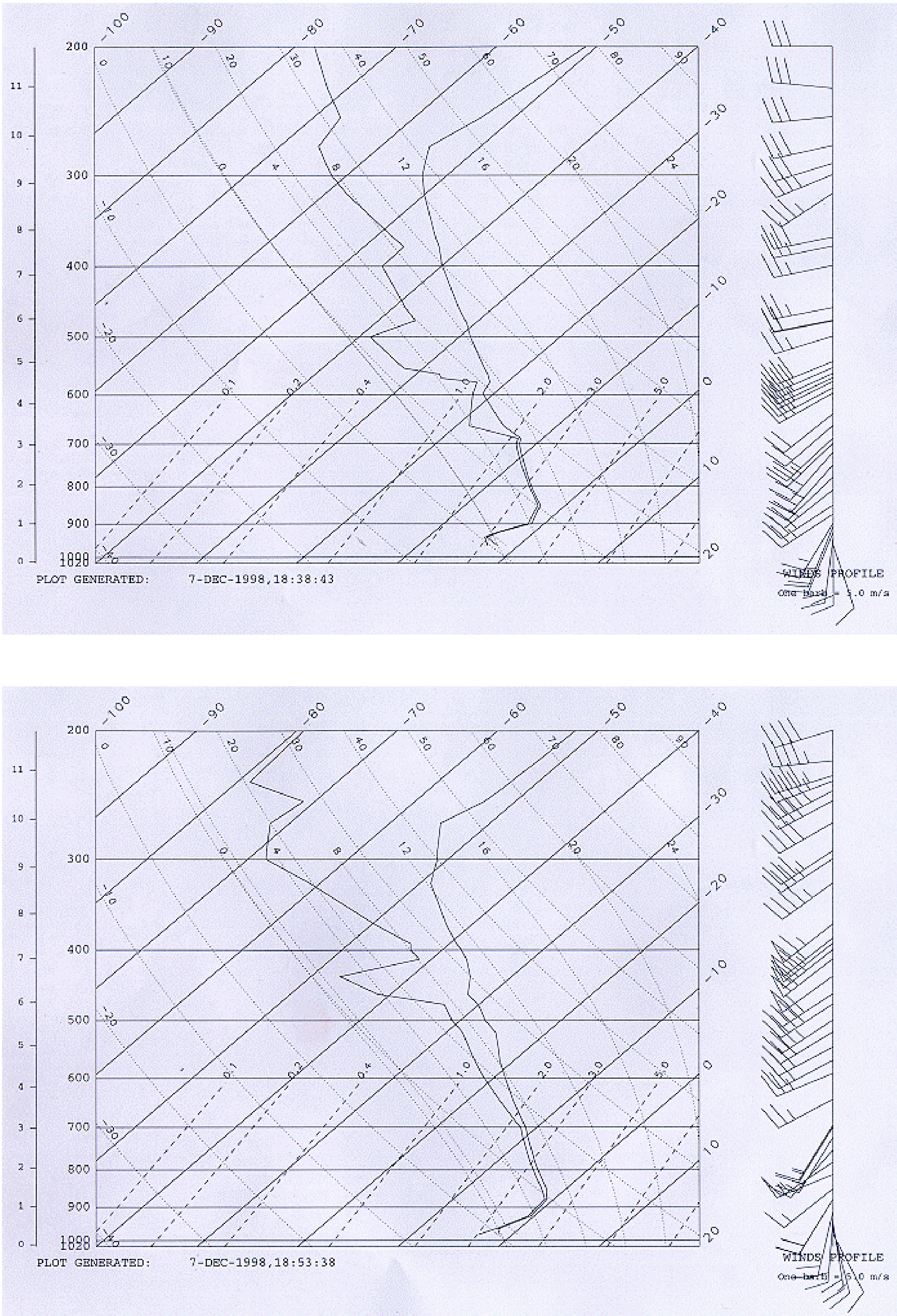


Figure 5 – Balloon-borne soundings from a) Alpena and b) Detroit at 980127, 1200 UTC.

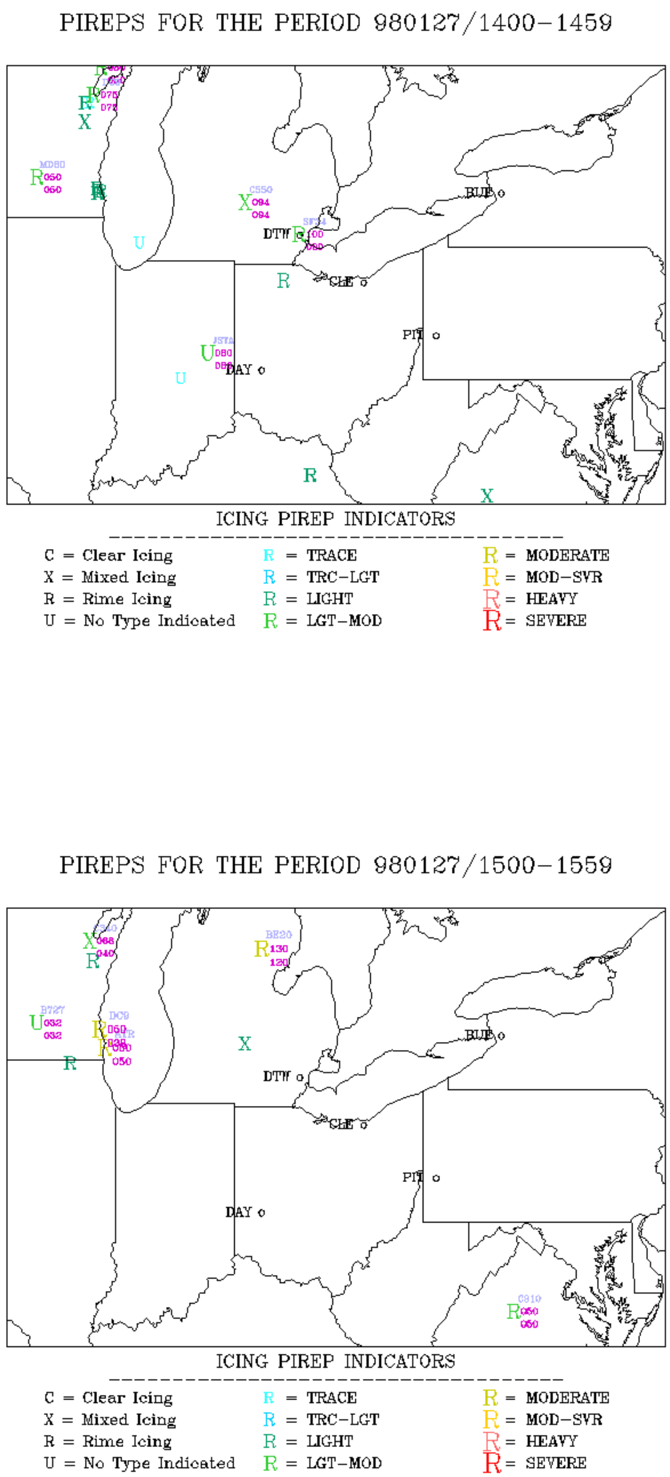
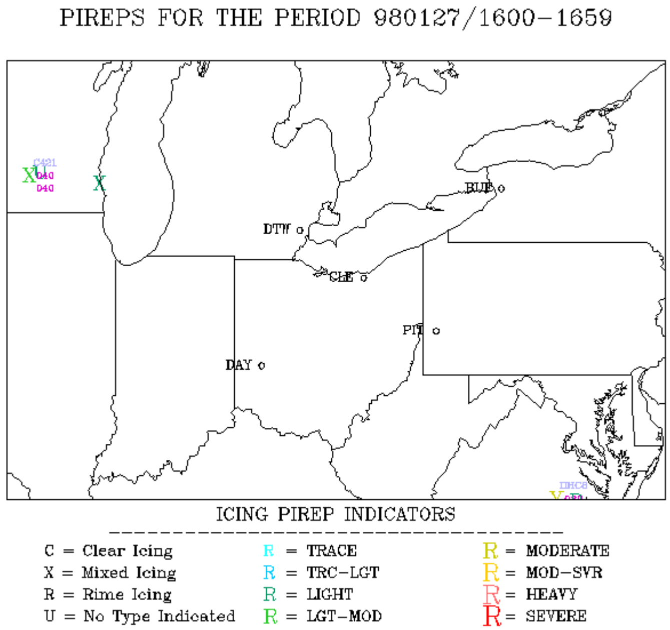


Figure 6 – Pilot reports of icing for 980127, a) 1400-1459 and b) 1500-1559 UTC.



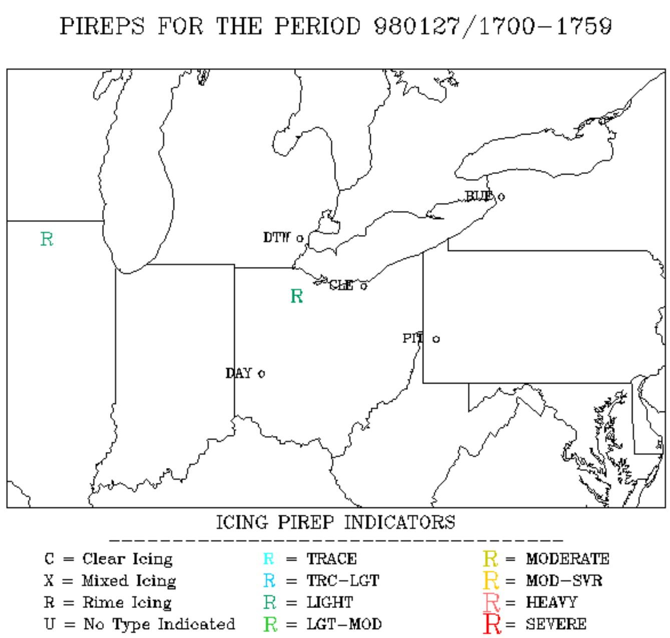


Figure 6 – Pilot reports of icing for 980127, c) 1600-1659 and d) 1700-1759 UTC.

January 29, 1998

Flight #1—Near Toledo, OH, and Jackson, MI, from 1821 to 2025 UTC.

Brief overview

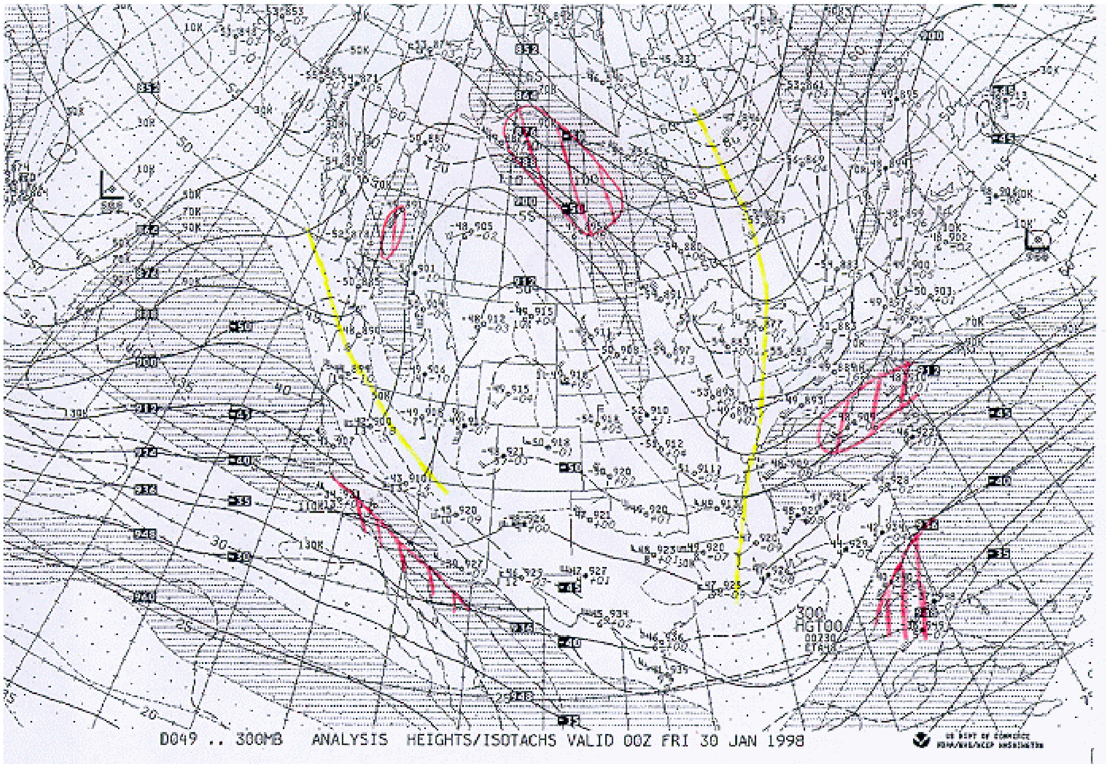
On this day, one flight was made within and between two areas of precipitation along the southern shore of Lake Erie and over southeastern Michigan. Cloud bases were near 3000' over Cleveland (CLE), and the freezing level was at 5000'. Small-droplet liquid water clouds, with LWC values as high as 0.8, were present to the west of CLE near 8000'. Within precipitation echoes, the clouds were deeper, LWC was typically fairly low (0-0.1), and ice crystals (dendrites and aggregates) were prevalent. Between the precipitation echoes, the LWC was usually above 0.3, cloud tops were lower and warmer (CTT near –5C), and mostly cloud-sized water droplets were observed. Some in-focus freezing drizzle (ZL) was observed near Toledo at around 1900 UTC just to the east of one precipitation area. Temperatures were near –4C, and LWC was between 0.0 and 0.3. Upon flying though the precipitation band en route to Jackson MI, ice crystals began to dominate and the ZL disappeared. A similar variety of conditions were observed on the return from Jackson to Cleveland, including more in-focus ZL just east of Toledo (near 2000 UTC). Mixed phase condtions were very apparent during several portions of the flight.

Relevant weather features

At 0000 UTC on 30 January (1200 UTC, 29 January maps were not available) an elongated trough ran to the south-southwest across western Michigan and western Indiana to the Louisiana coast (Fig. 1). The main 500 mb trough mirrored this, and a secondary trough ran southeastward from Alpena MI to Erie PA. Some moist conditions existed to the northeast of that trough, while rather dry conditions were found over Ohio and Indiana. At 700 mb, a low was centered over Lake Huron, while a trough ran southwestward from it across Ohio. Moist air surrounded the low and trough across Ohio, eastern Michigan, western Pennsylvania, and to the north. Cold advection was prevalent across the area. A similar scenario was in place at 850 mb, but the low and trough/cold front were slightly further to the east. Cold advection was primarily found to the west of the trough, across Michigan, northwestern Ohio, and Indiana, while no strong temperature advection was evident over eastern Ohio. Moist conditions accompanied the trough southward to the Gulf Coast.

Surface charts (Fig. 2) showed a 1002 mb low centered near Detroit at 1800 UTC (the 2100 UTC map was not available), with a cold front across Ohio, and a warm front across southeastern Ontario and western New York. The low and cold front moved toward the east with time. The Twin Otter sampled areas within and between the pockets of rain and snow that moved across the area (Fig. 3). Infrared and visible satellite imagery (Fig. 4) showed an area of widespread, warm clouds (CTTs of -5C to -10C) with streaks and pockets of deeper, colder clouds rolling over them. The areas of colder cloud tops (CTTs < -15C) roughly matched the locations of the radar echoes across Ohio and Michigan during the period of interest.

A sounding taken at Lincoln IL at 1200 UTC (Fig. 5) passed through the warm, low-level cloud that moved eastward into Ohio and Michigan during the day. Conditions gradually dried out at Lincoln, leaving only a very thin cloud there by 0000 UTC. The reverse was true at Wilmington, as dry conditions in southwestern Ohio moistened with time, and a thick, warm cloud (CTT near -9C) formed there. The same moisture moved into Detroit by 0000 UTC after some deep, cold, snowy clouds that were present at 1200 UTC had moved out. Moderate and light severity PIREPs were found between 3,000' and 10,000' within the widespread low clouds, especially outside of, and along the edges of the radar echoes (Fig. 6).



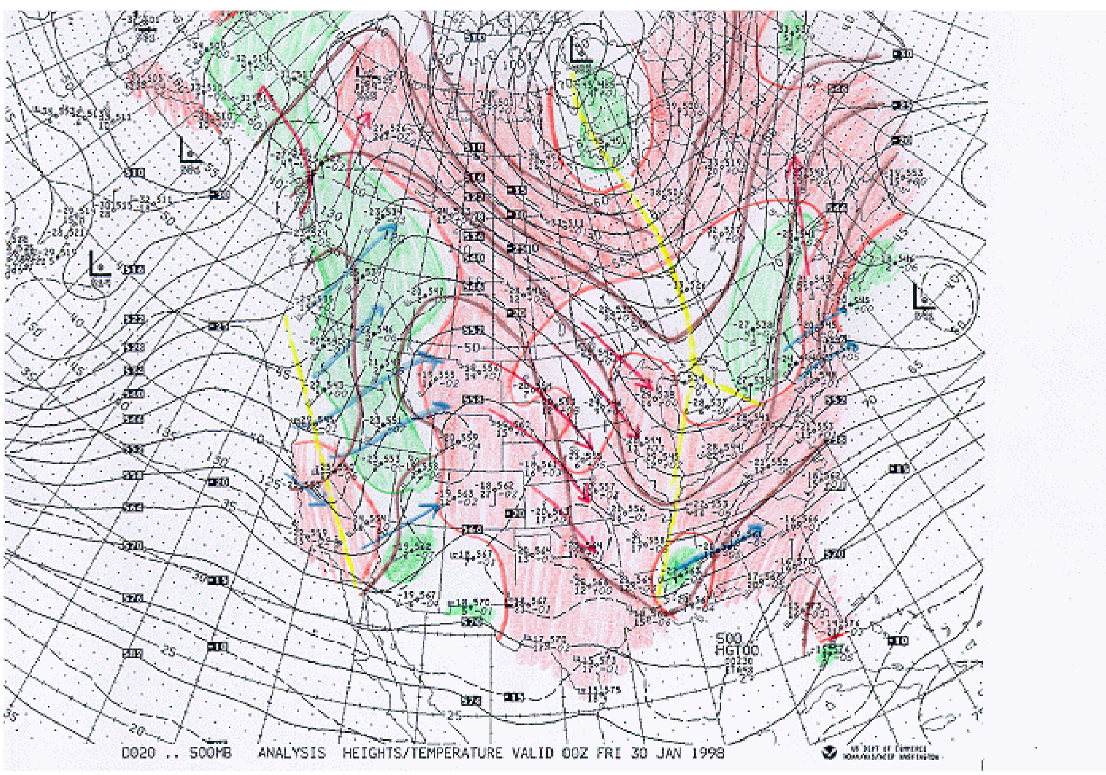


Figure 1 – Upper-air charts for 980129, 1200 UTC at a) 300 and b) 500 mb.

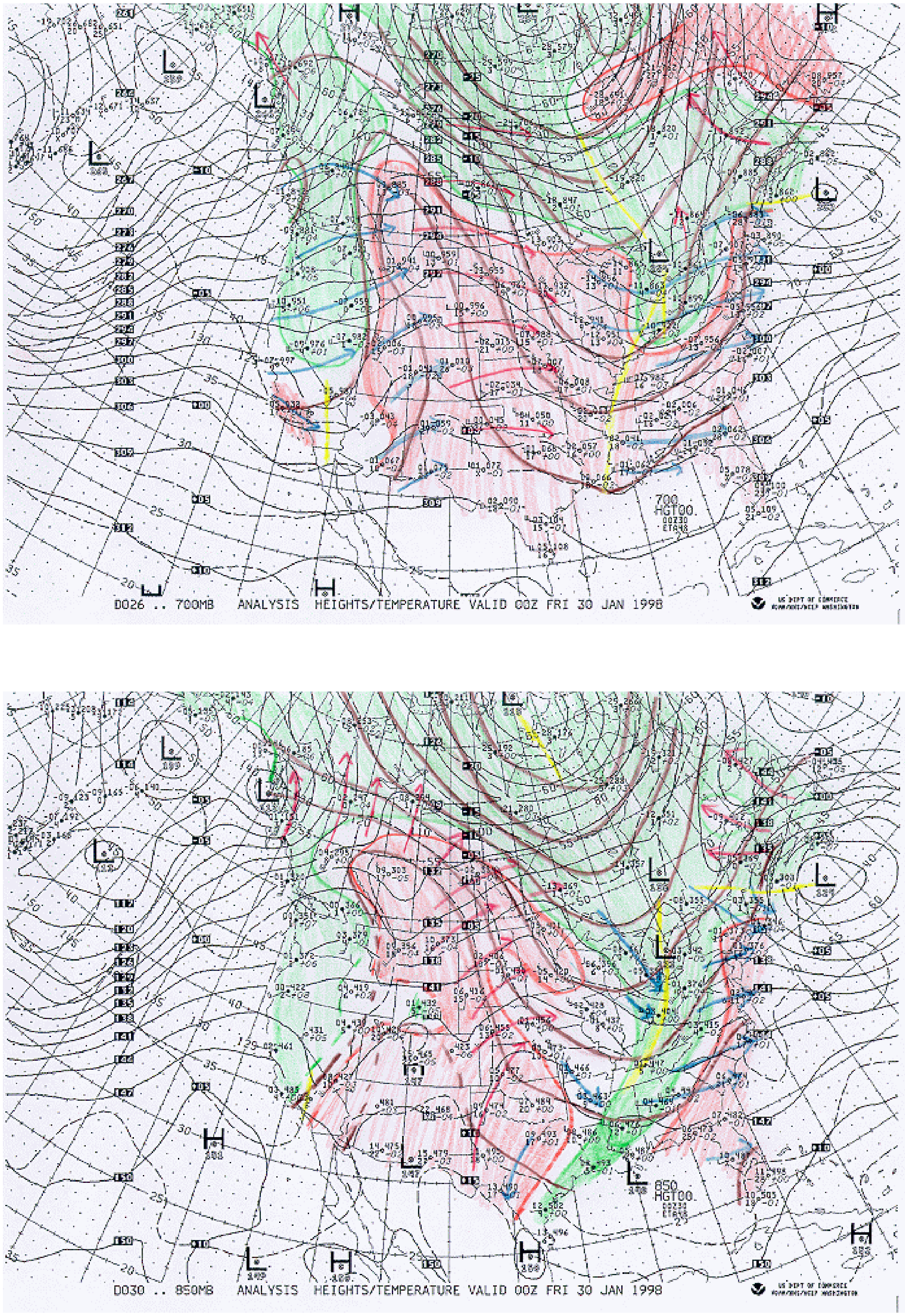


Figure 1 – Upper-air charts for 980129, 1200 UTC at c) 700 and d) 850 mb.

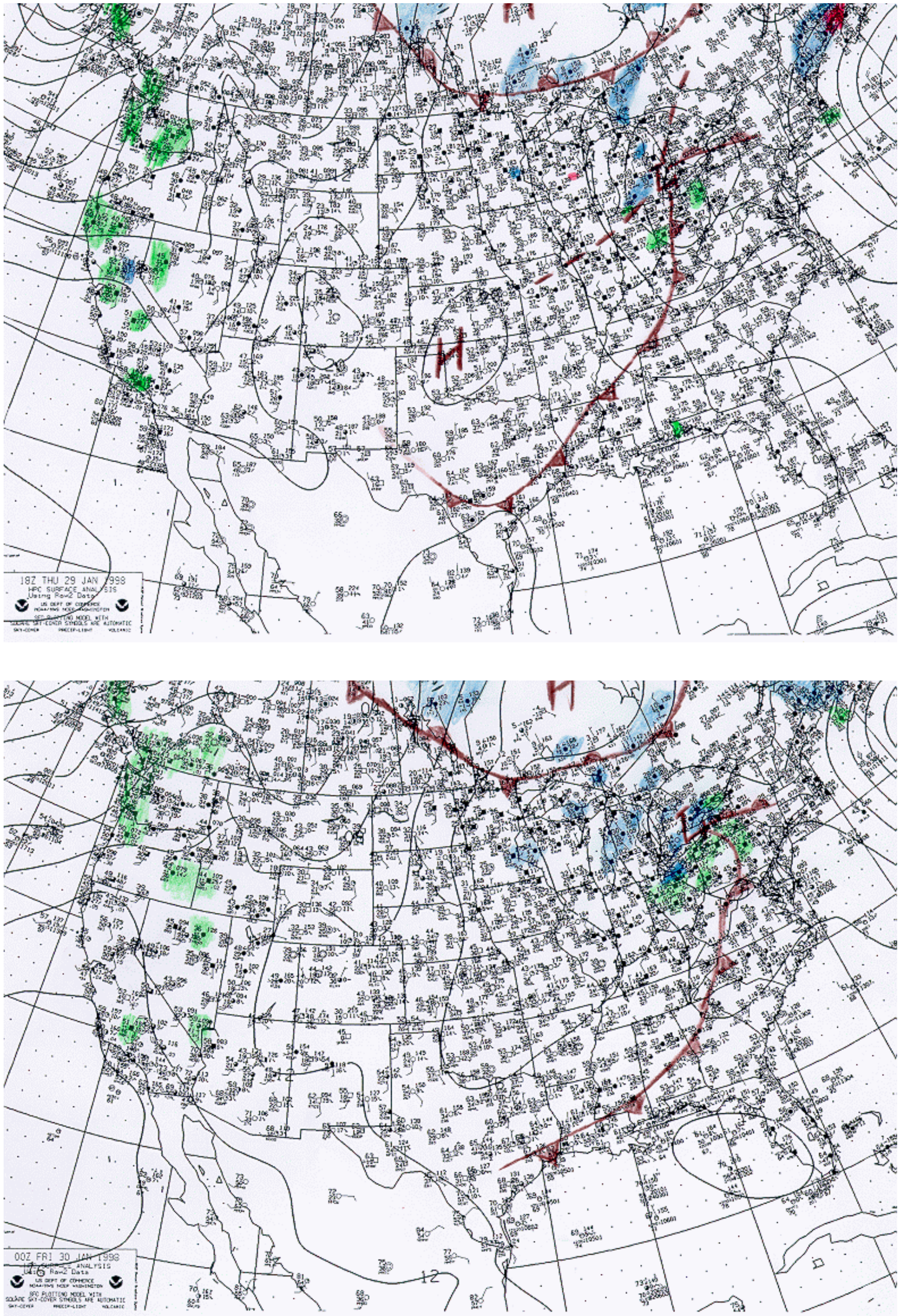
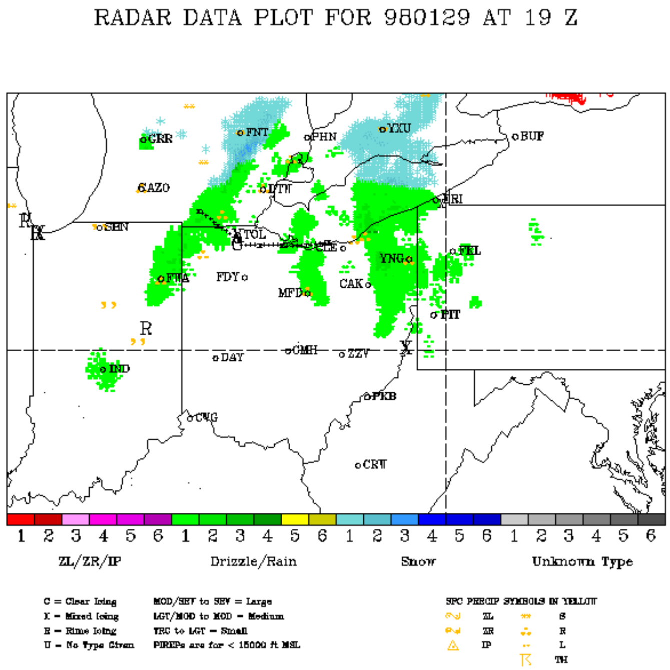


Figure 2 – Surface charts for a) 980129, 1800 and b) 980130, 0000 UTC.



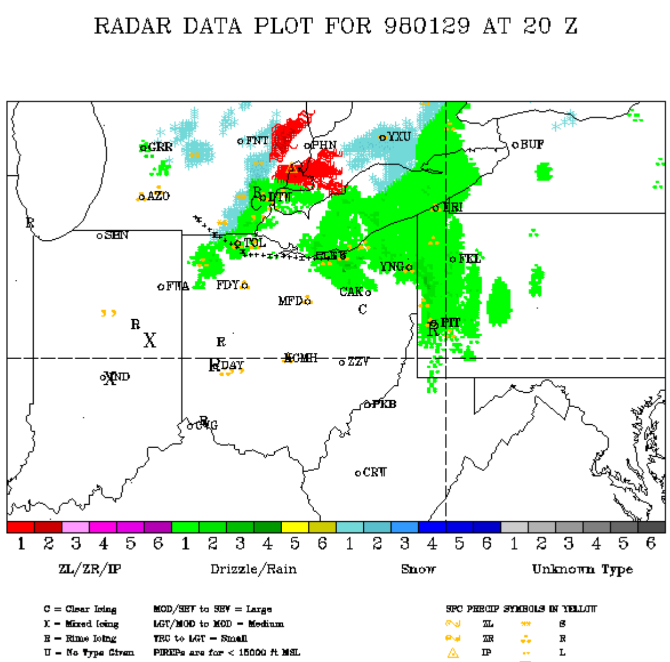


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980129, a) 1900 and b) 2000 UTC.

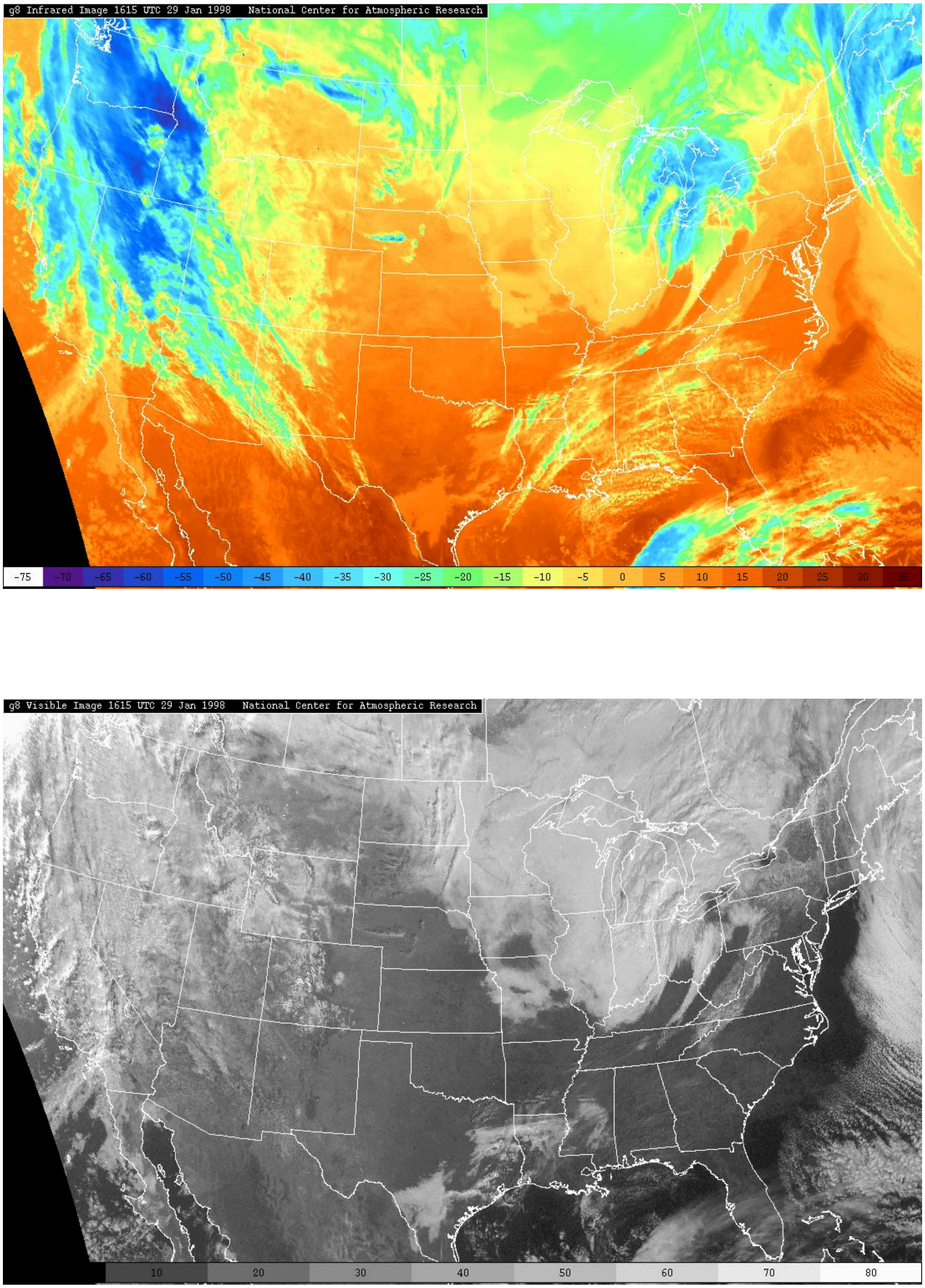
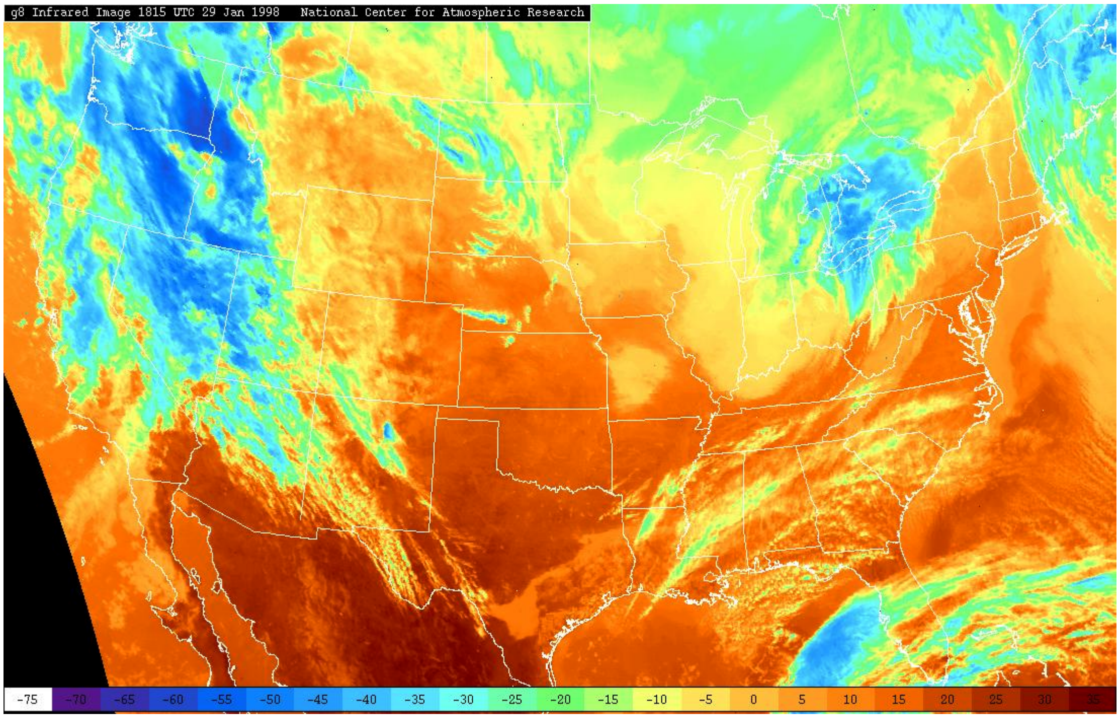


Figure 4 – GOES-8 a) infrared and b) visible satellite images for 980129, 1615 UTC.



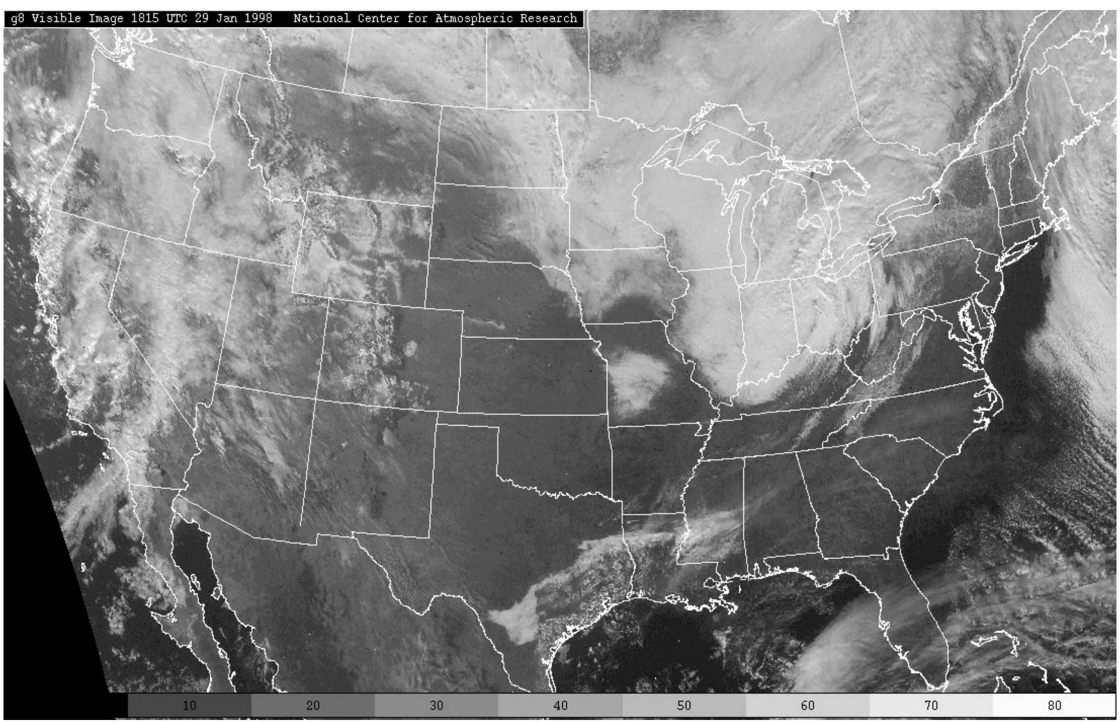
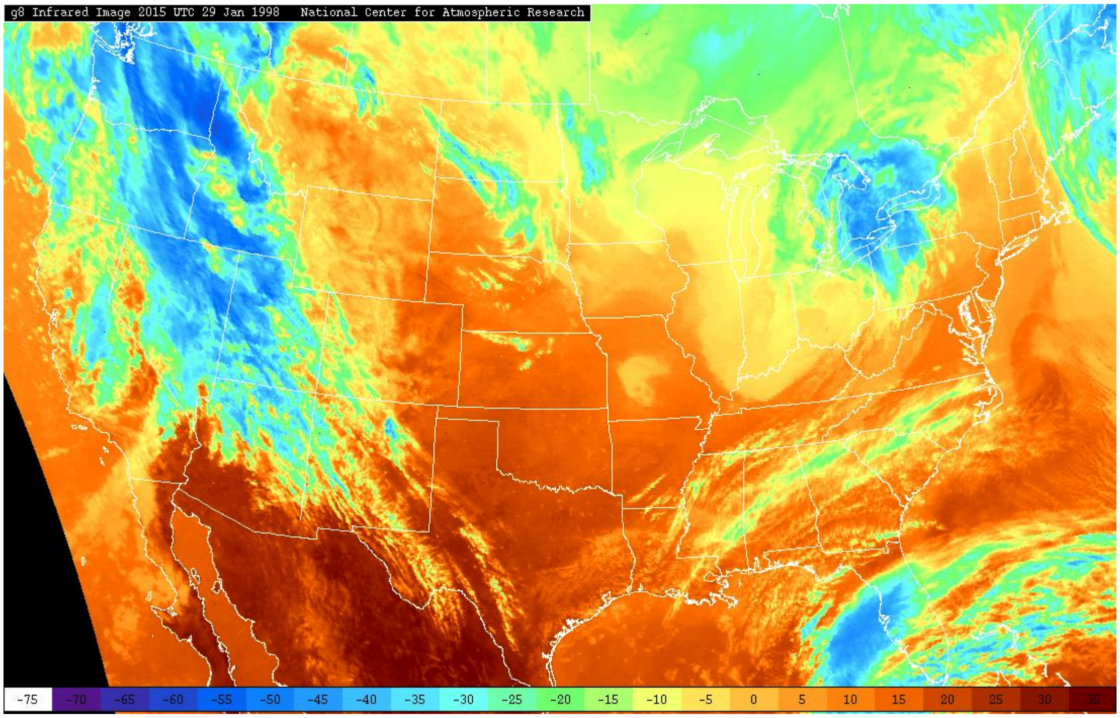


Figure 4 – GOES-8 c) infrared and d) visible satellite images for 980129, 1815 UTC.



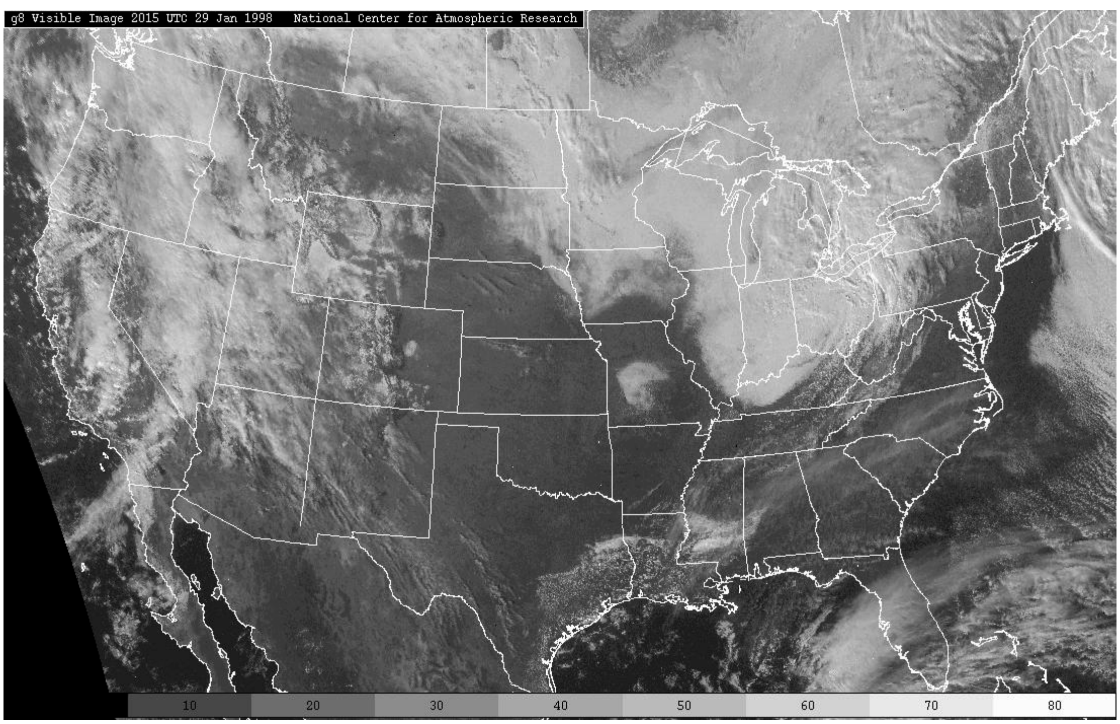
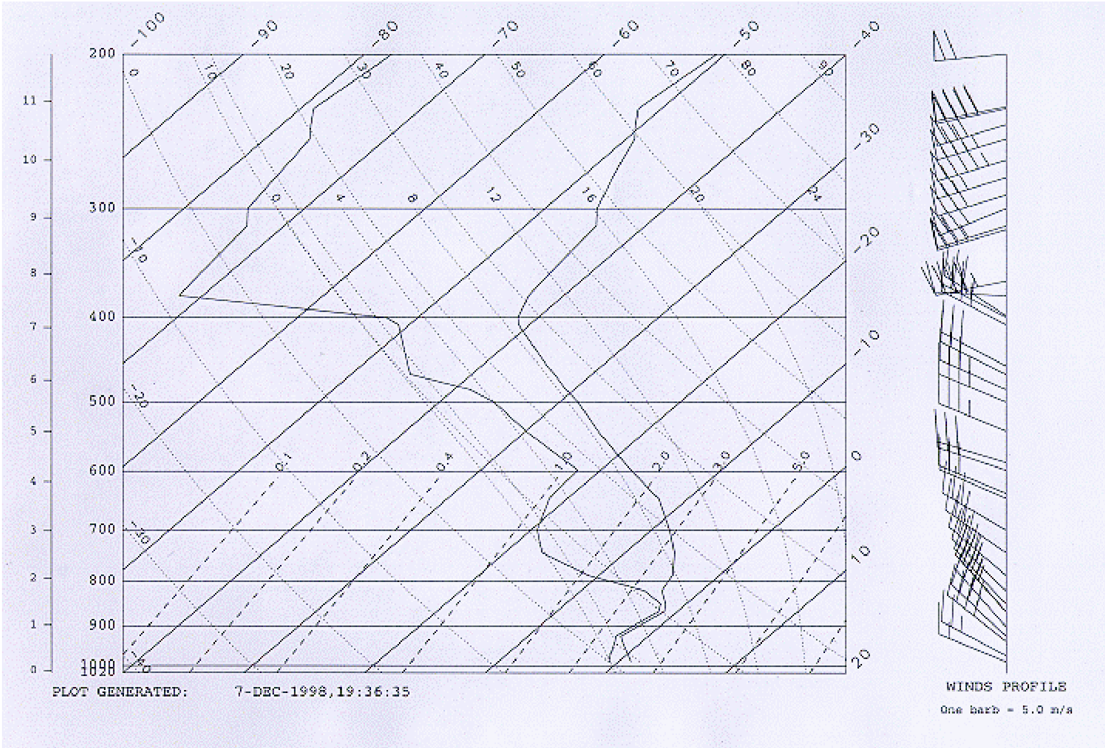


Figure 4 – GOES-8 e) infrared and f) visible satellite images for 980129, 2015 UTC.



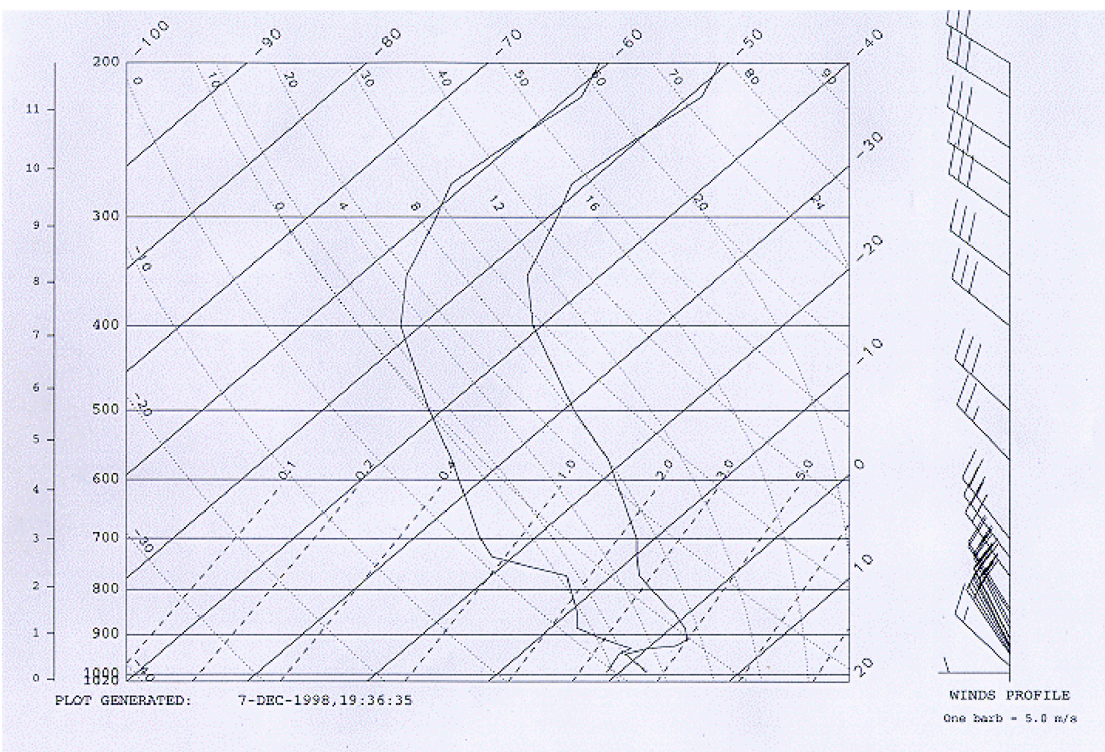
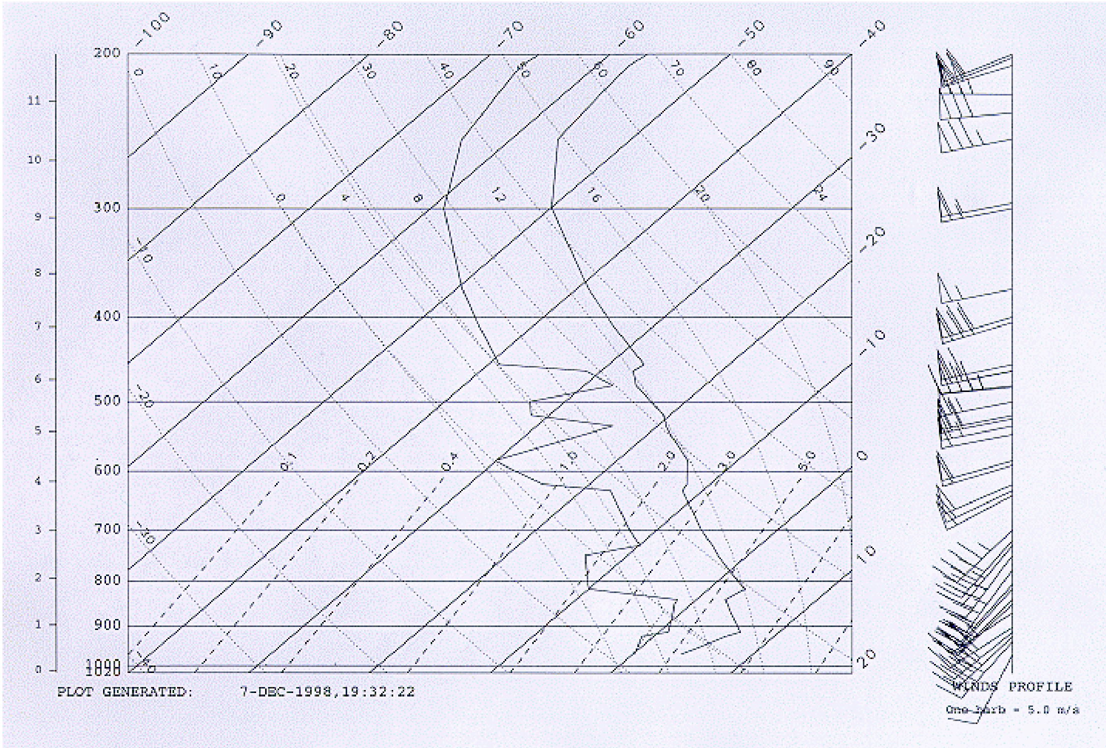


Figure 5 – Balloon-borne soundings from Lincoln IL at a) 980129, 1200 and b) 980130, 0000 UTC.



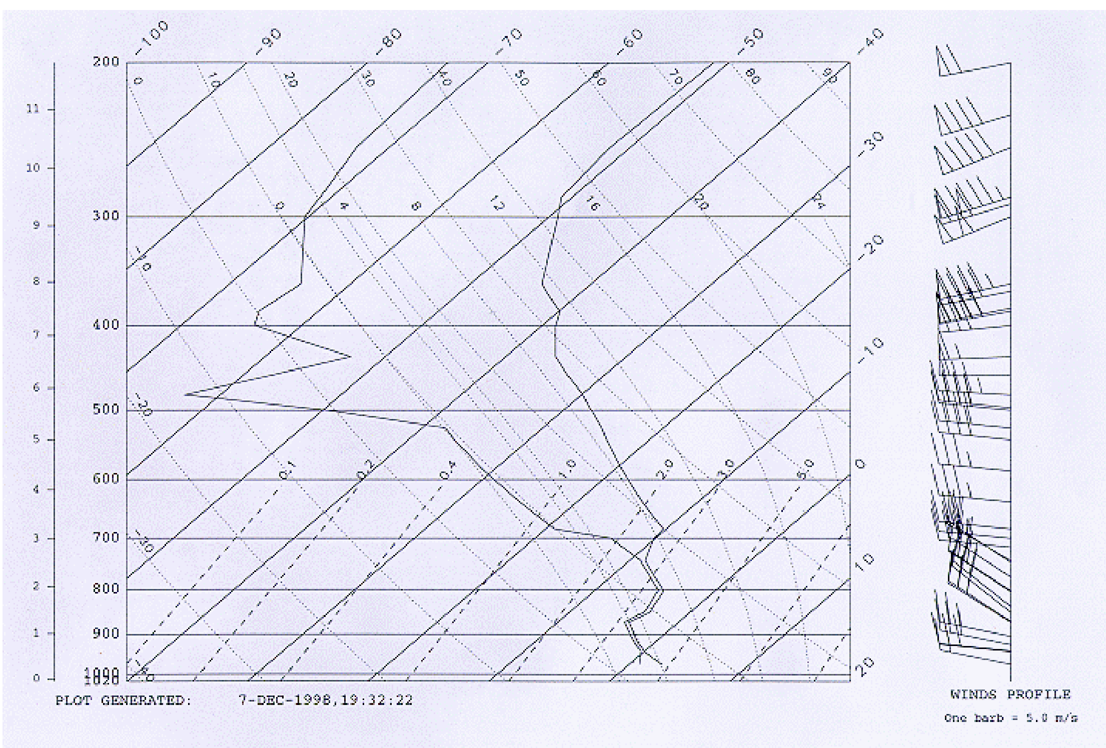
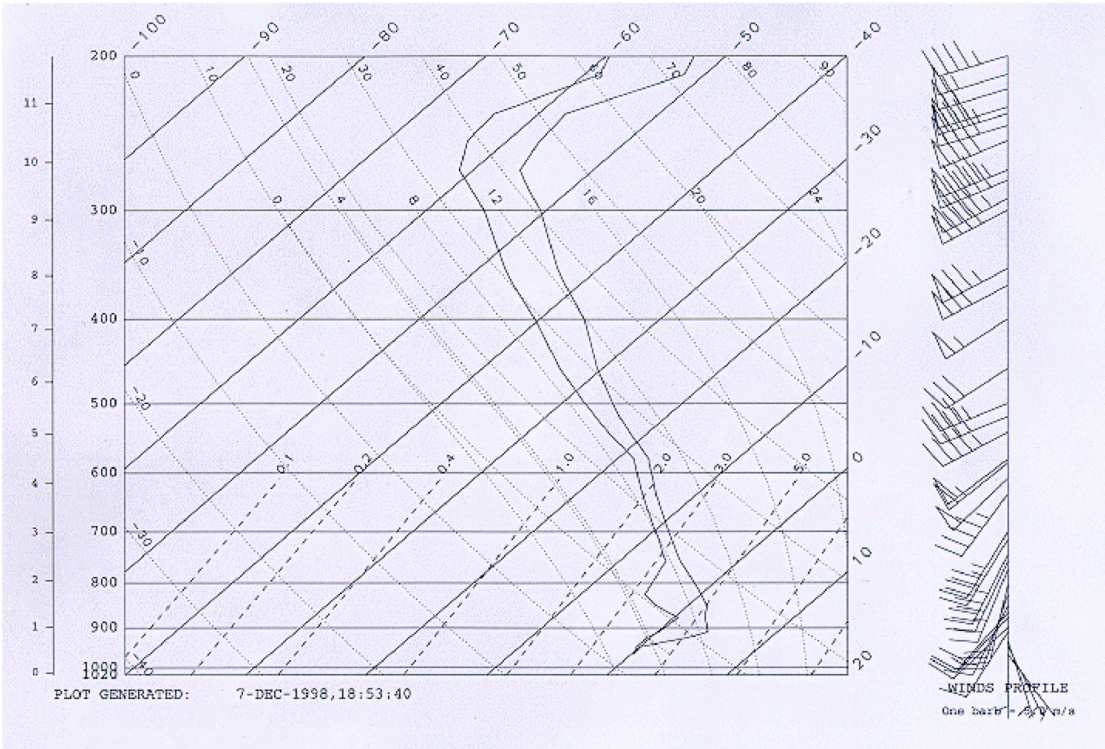


Figure 5 – Balloon-borne soundings from Wilmington at c) 980129, 1200 and d) 980130, 0000 UTC.



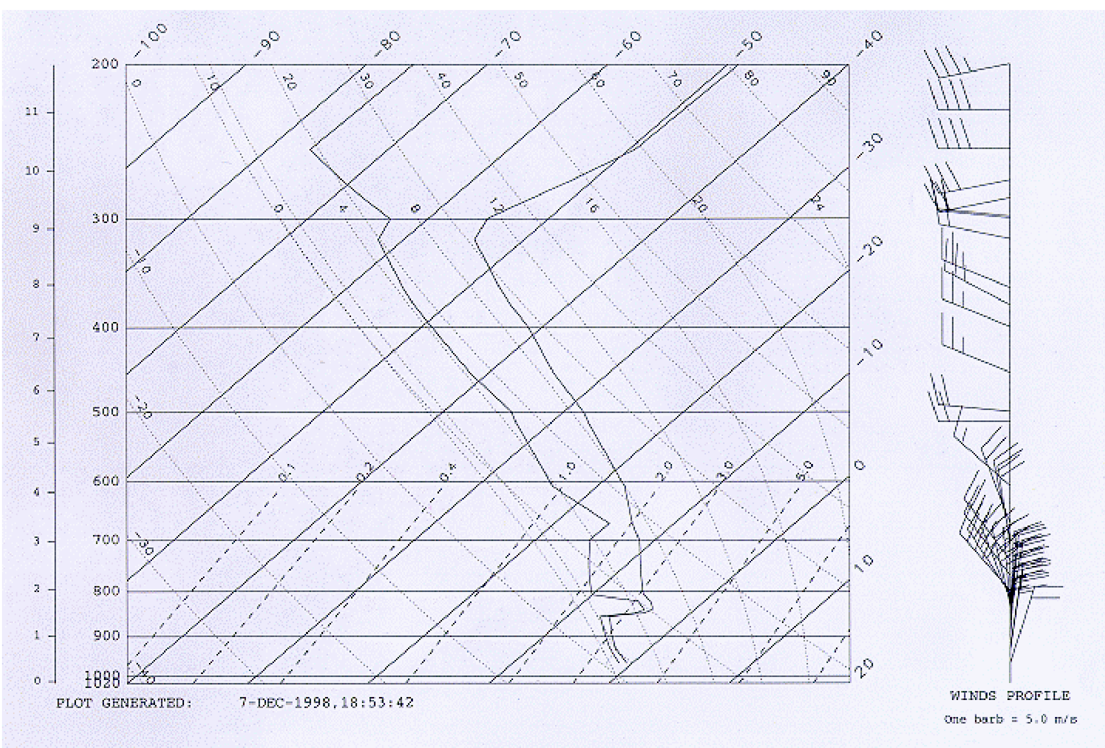
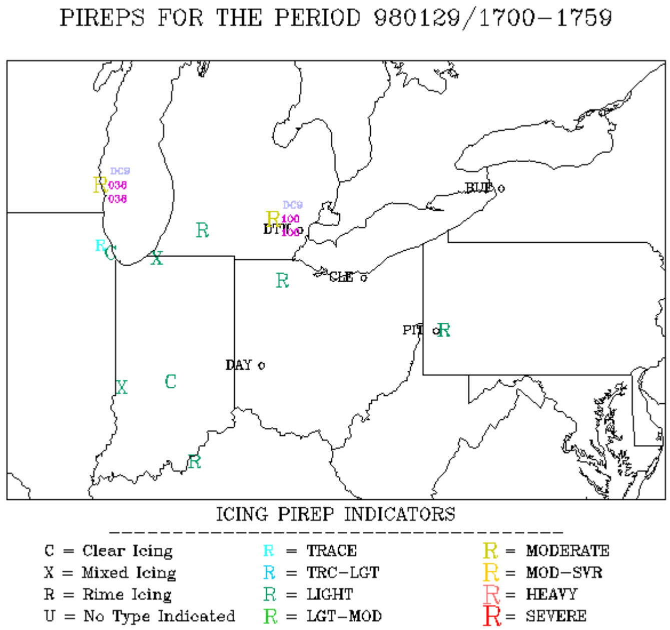


Figure 5 – Balloon-borne soundings from Detroit at e) 980129, 1200 and f) 980130, 0000 UTC.



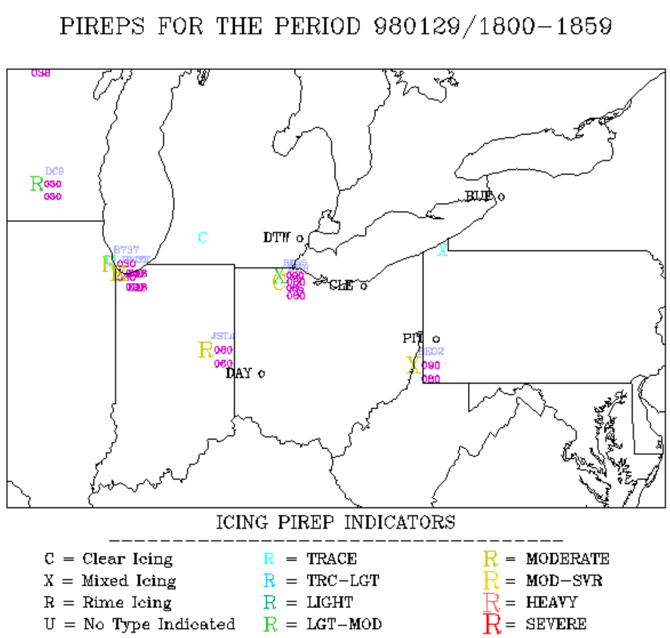


Figure 6 – Pilot reports of icing for 980129, a) 1700-1759 and b) 1800-1859 UTC.

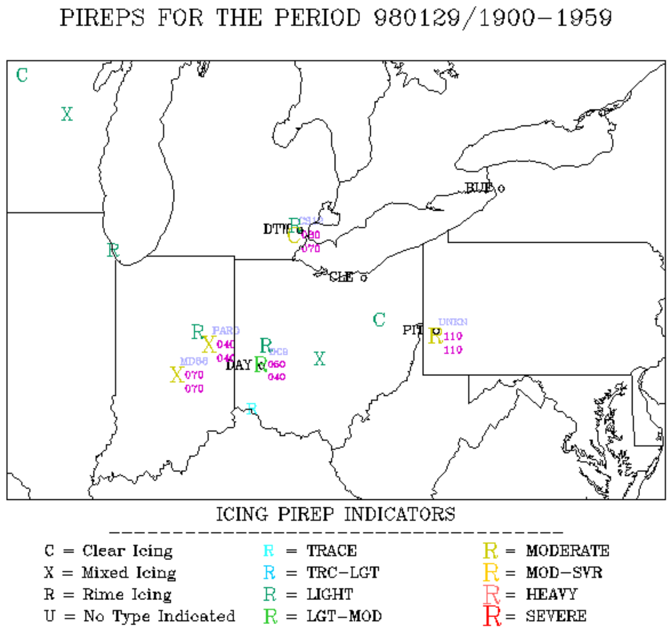


Figure 6 – Pilot reports of icing for 980129, c) 1900-1959 UTC.

January 30, 1998

Flight #1—Over Canton-Akron and Youngstown, OH, from 1310 to 1431 UTC.

Brief overview

On this day, one flight was made into small-droplet, very light freezing drizzle (ZL), and mixed-phase clouds downwind of Lake Erie. Initial takeoff was made into ice crystals, including some aggregates, over Cleveland. Cloud base was at 2400', and had a temperature of –4C. As the Twin Otter flew southeast toward Canton-Akron (CAK), LWC increased with height to 0.8 near cloud top (5800', CTT = –11C). Mixed conditions were observed on descent through the clouds over CAK, and some ZL (mixed with ice crystals) was found within and below cloud bases (2700'). Temperature was fairly steady (-5/-6C) and LWC gradually rose from 0.1 to 0.15 as the aircraft flew northeast toward Youngstown (YNG) at about 3000'. A similar profile of LWC was found during a missed approach and flight through cloud top (CTT = -11C) at YNG. ZL and ice crystals were much less evident, but still present there. Another sounding was made on final approach into Cleveland, where slightly lower water contents and more crystals were present.

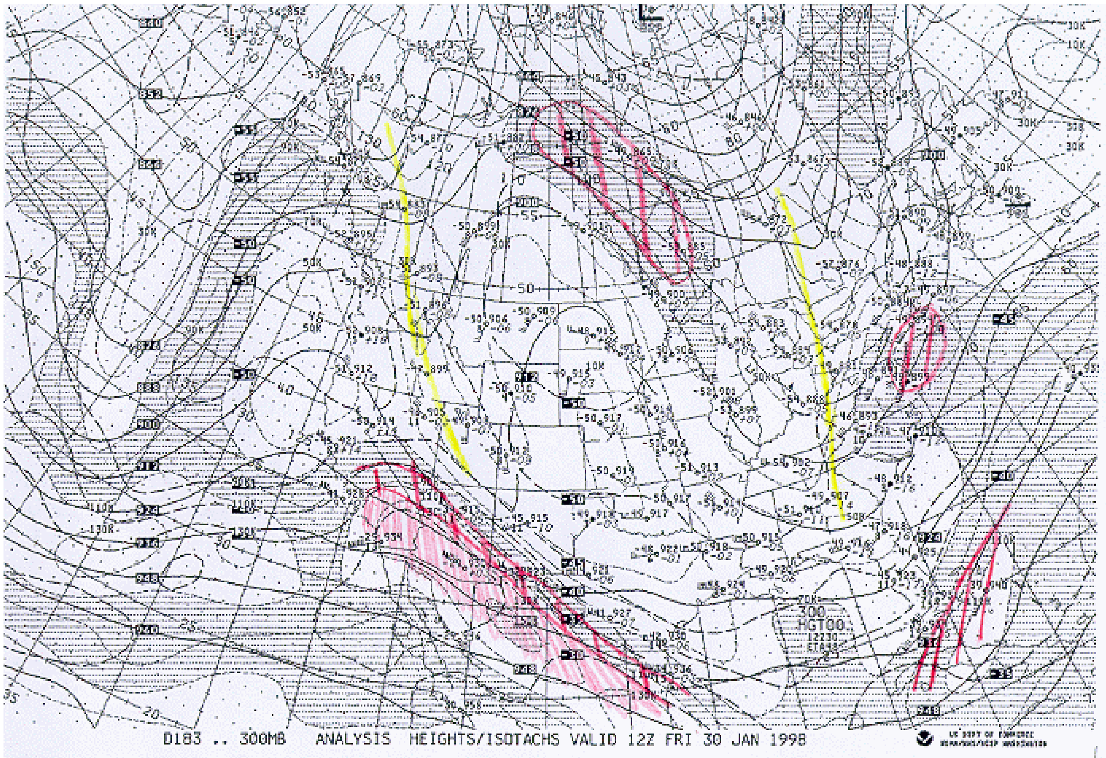
Relevant weather features

A 300 mb trough ran from north to south through eastern Ohio at 1200 UTC (Fig. 1). A similar trough was found slightly to the east at 500 mb, with dry conditions to its west, and moist air on its eastern side from Buffalo northward. The trough was yet further to the east at 700 mb. Cold advection covered Michigan, Ohio, and states to their east. Saturated air with temperatures near -14C drooped across Pennsylvania, Lake Huron, and areas to the north and east. Rather dry air was found elsewhere. At 850 mb, the saturated air sagged further to the southwest, across most of Ohio and Michigan. Temperatures were between -5C and -8C at this level. Cold advection was present over eastern Ohio, behind the trough/cold front. Surface charts (Fig. 2) show that this front moved eastward across Pennsylvania with time. A stationary front was in place just to the north of Lake Erie.

An NCAR class sounding taken at Cleveland (Fig. 3) ascended through a cloud layer from 925 to 820 mb. The cloud deck had a moist-adiabatic temperature profile that was strongly capped at cloud top, where the CTT was about -10C. NW winds dominated the entire sounding, placing northeast Ohio directly downwind of the unfrozen Lake Erie. The 1200 UTC sounding at Wilmington showed the shallower nature of the clouds to the southwest, while the Buffalo sounding indicated the deeper, colder clouds to the northeast. Pittsburgh had a cloud layer similar to that seen at Cleveland, with a slightly more stable lapse rate. Infrared satellite imagery (Fig. 4) clearly indicated a southwest to northeast gradient in cloud top temperature across Ohio.

Surface observations (Fig. 2) and radar data (Fig. 5) indicated snow near Buffalo and over Michigan, as well as widespread light freezing drizzle and light snow across northeastern Ohio, western

Pennsylvania, and West Virginia. Little or no radar echo (> 18 dBZ) was observed in those areas. Mostly non-precipitating, overcast conditions existed over Indiana and western Ohio. The Canton-Akron ASOS reported some freezing rain (misreported freezing drizzle), while Youngstown and other sites in Pennsylvania reported freezing drizzle correctly. Moderate and greater severity PIREPs were common across the region (Fig. 6). The icing altitudes reflected the rising cloud top heights toward the northeast. Most were rimed and mixed in type, but a few clear icing PIREPs were made.



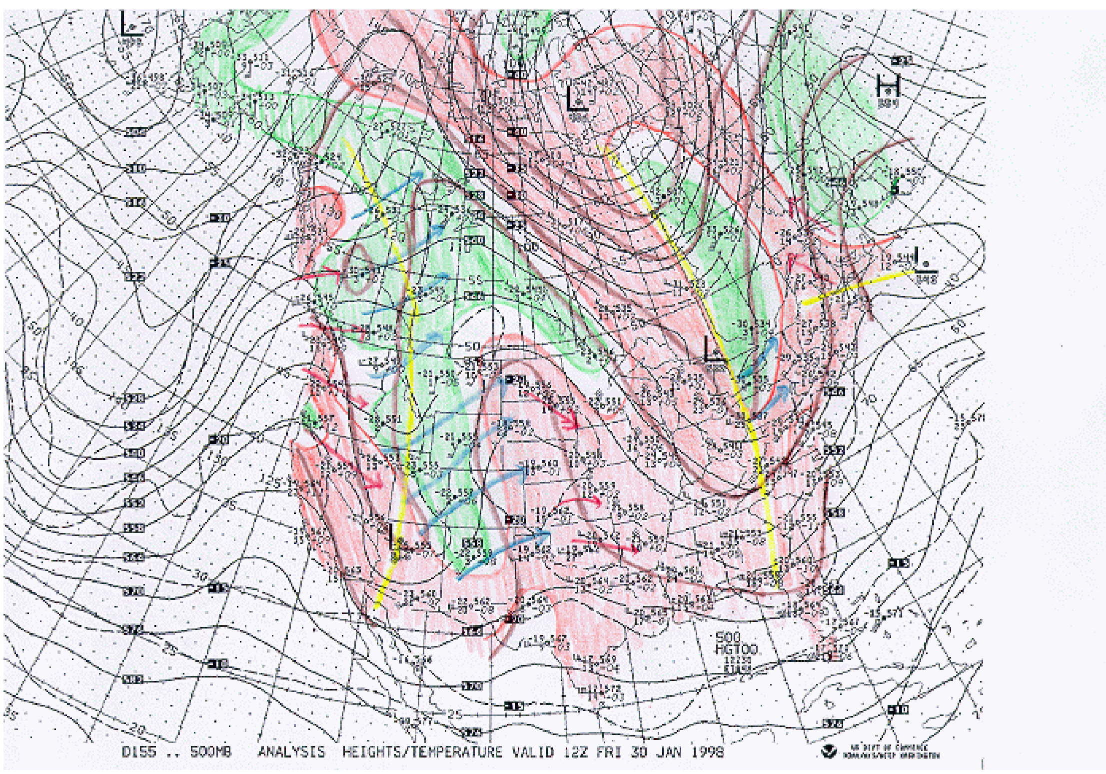
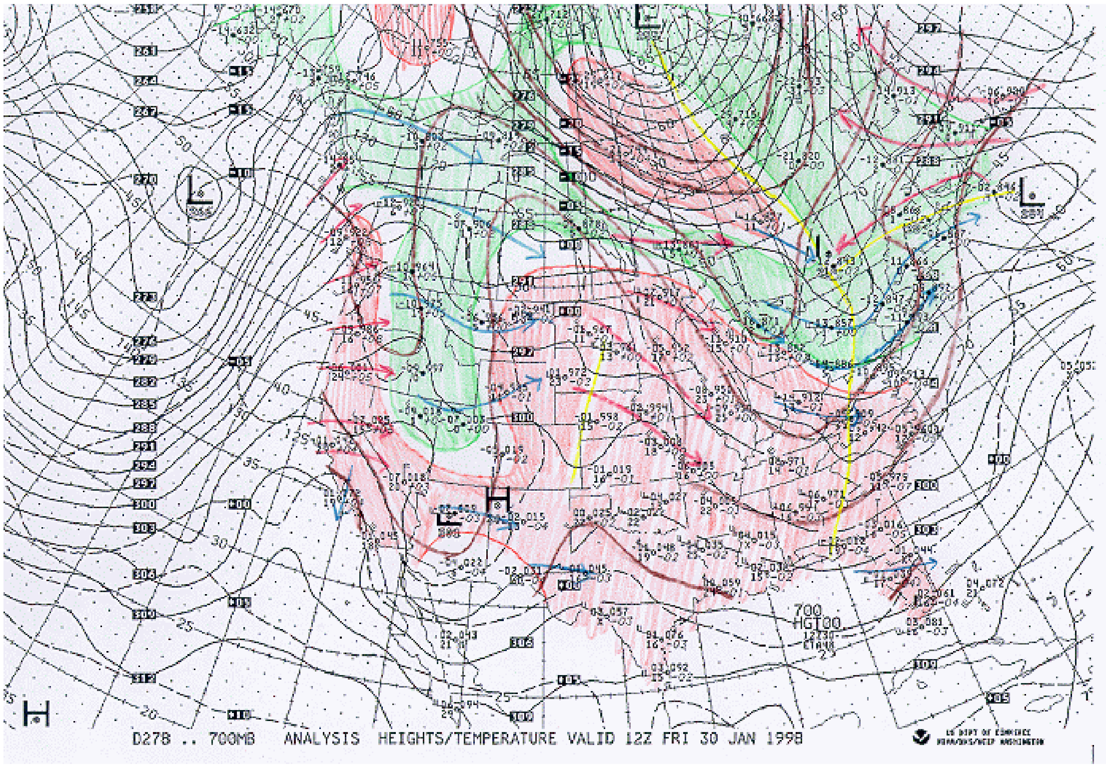


Figure 1 – Upper-air charts for 980130, 1200 UTC at a) 300 and b) 500 mb.



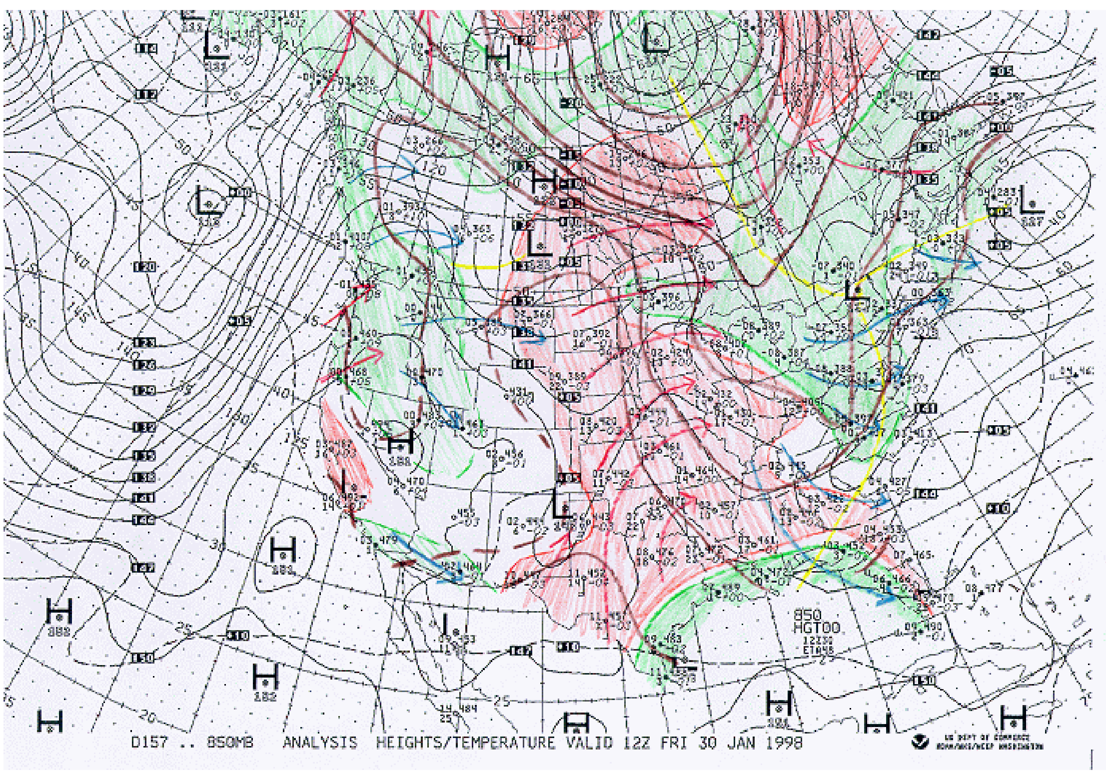


Figure 1 – Upper-air charts for 980130, 1200 UTC at c) 700 and d) 850 mb.

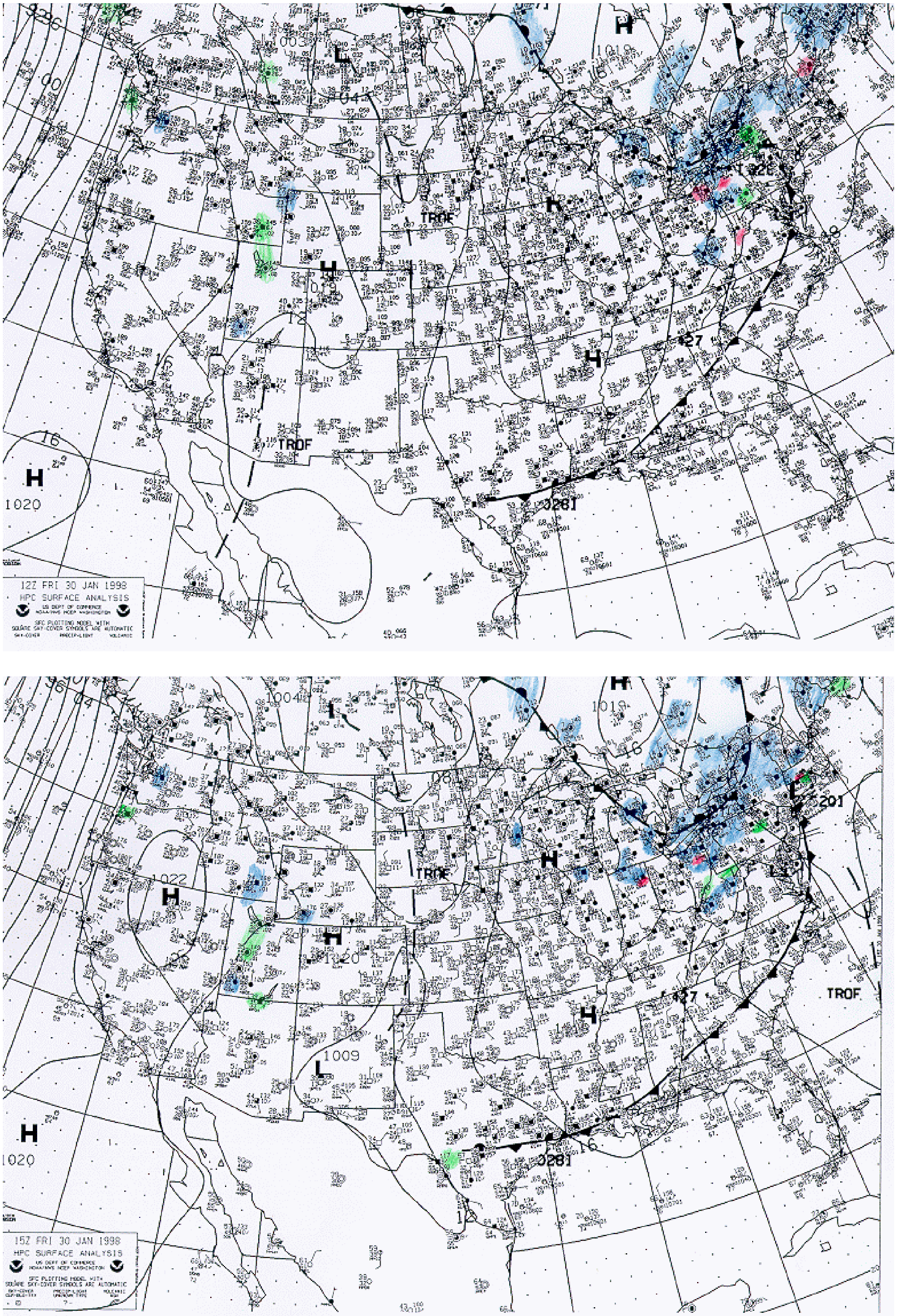
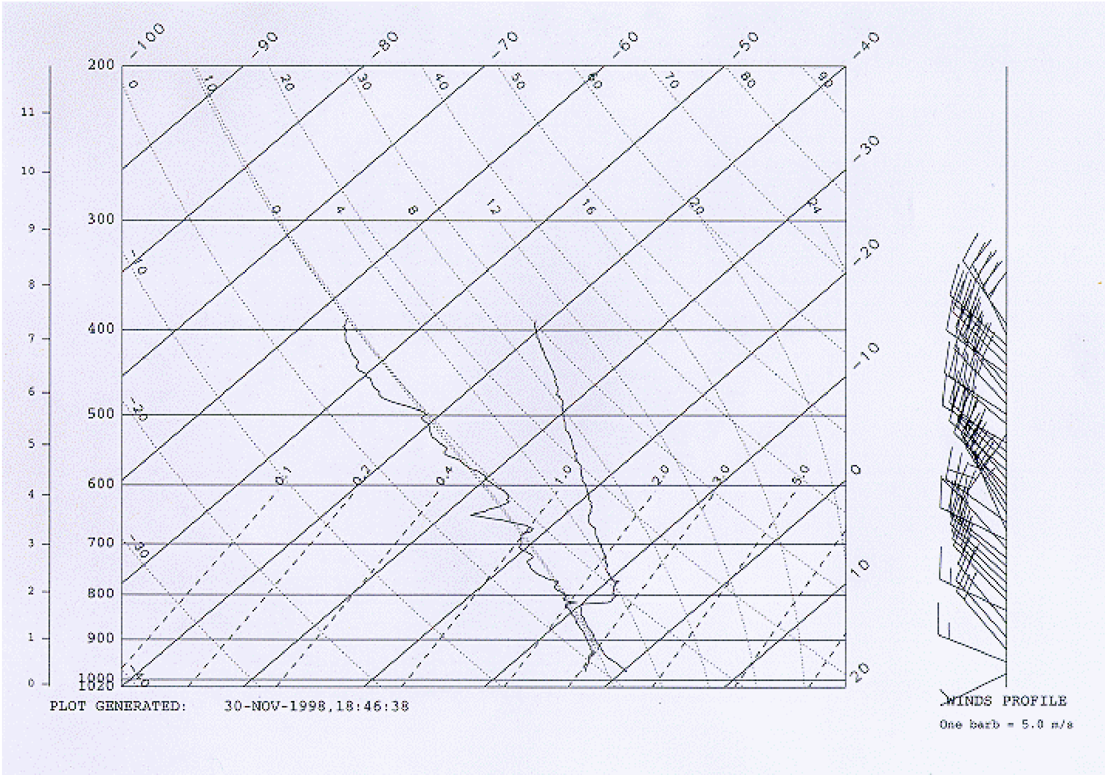


Figure 2 – Surface charts for 980130, a) 1200 and b) 1500 UTC.



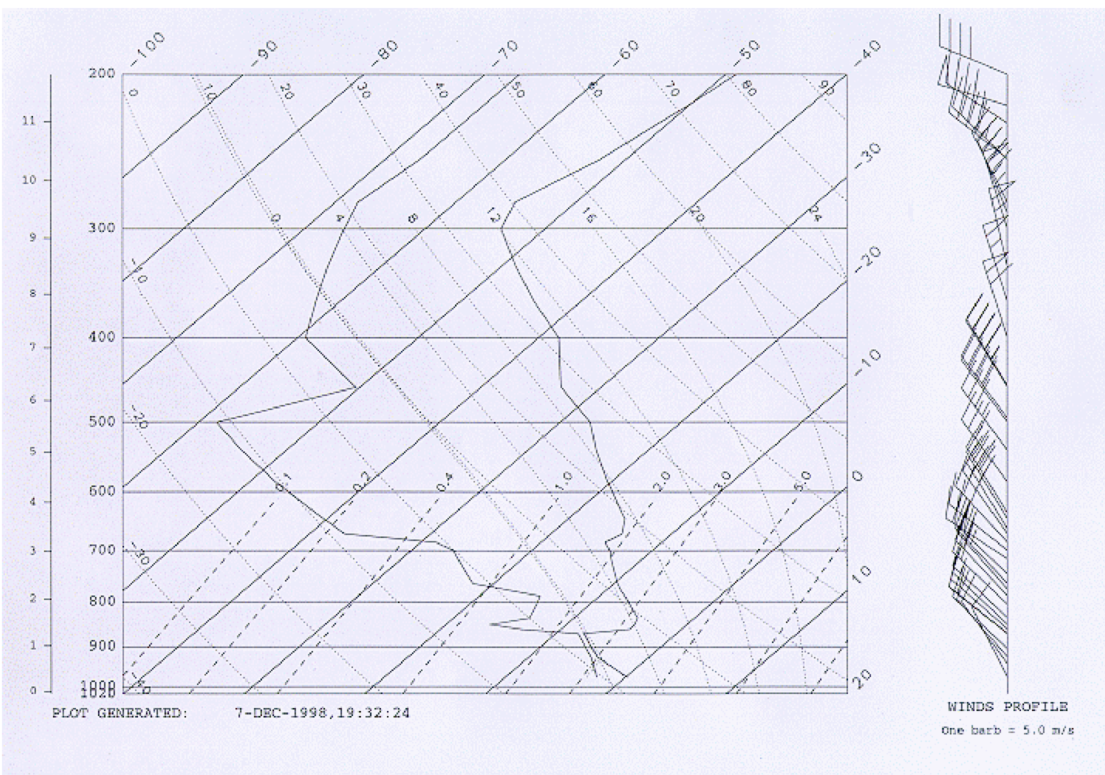
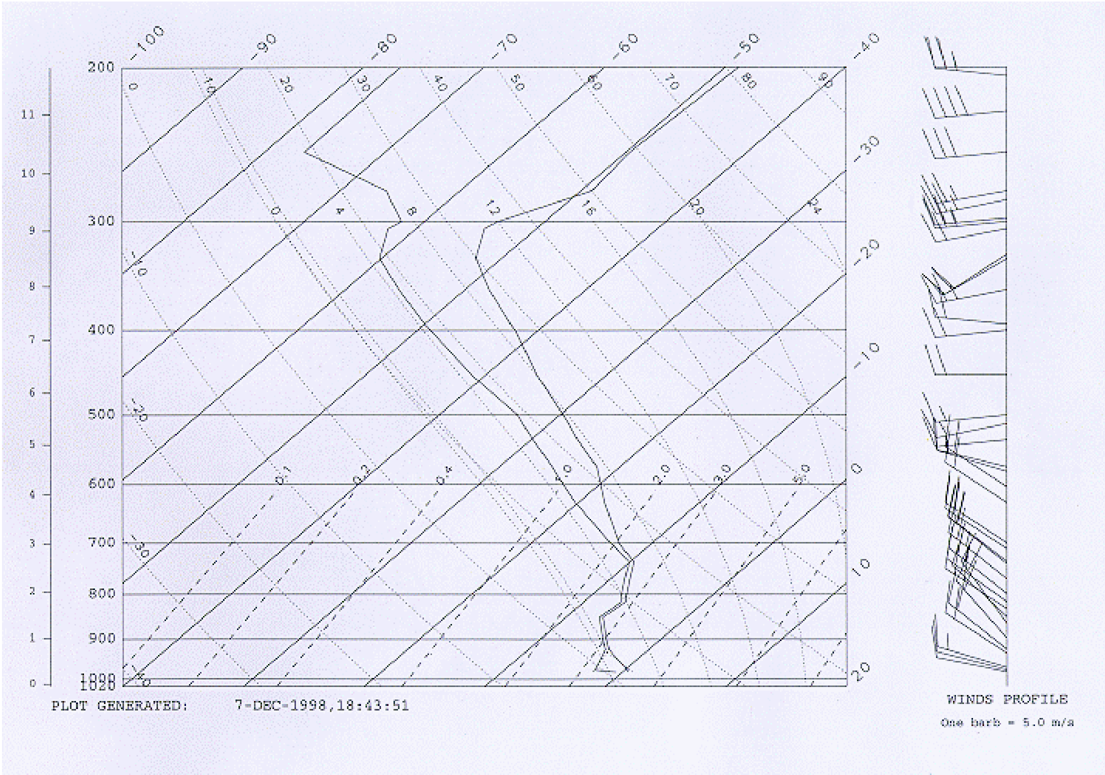


Figure 3 – Balloon-borne soundings from a) Cleveland (NCAR CLASS) at 980130, 1129 UTC and b) Wilmington at 980130, 1200 UTC.



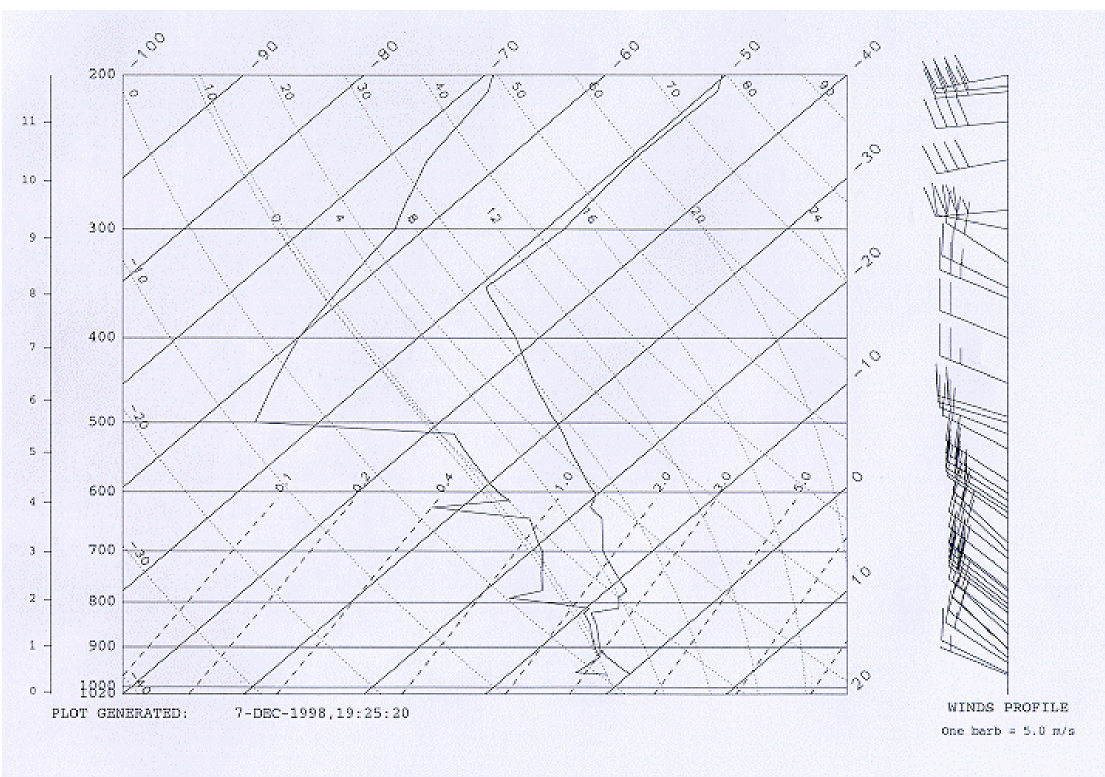


Figure 3 – Balloon-borne soundings from c) Buffalo and d) Pittsburgh at 980130, 1200 UTC.

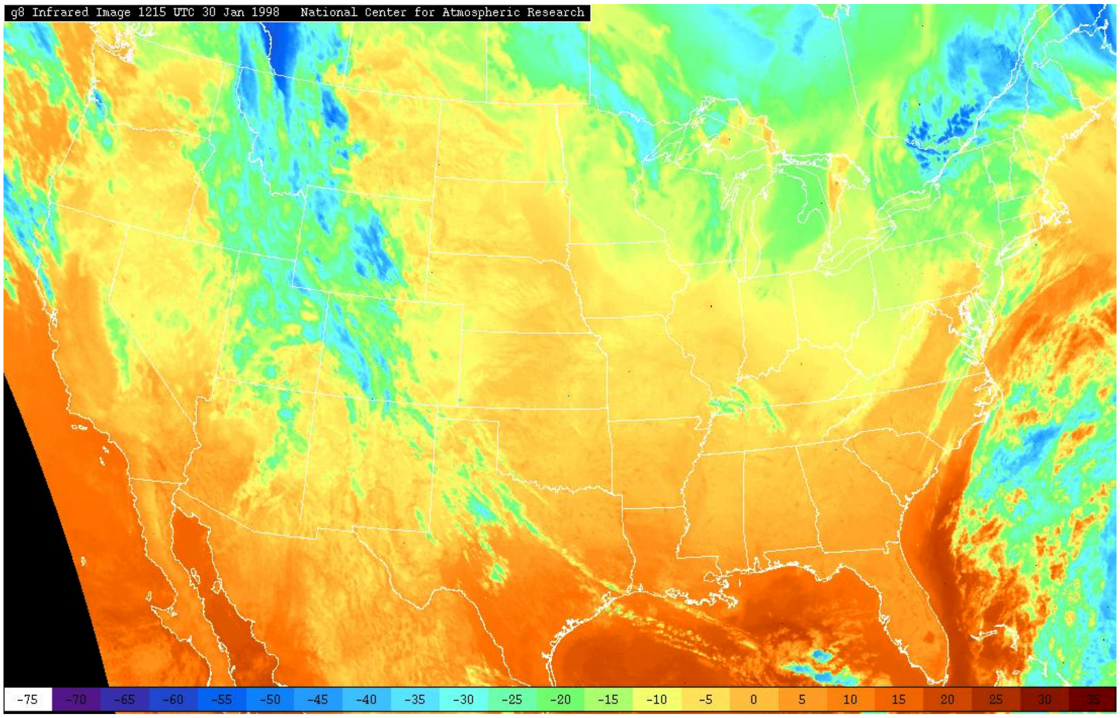
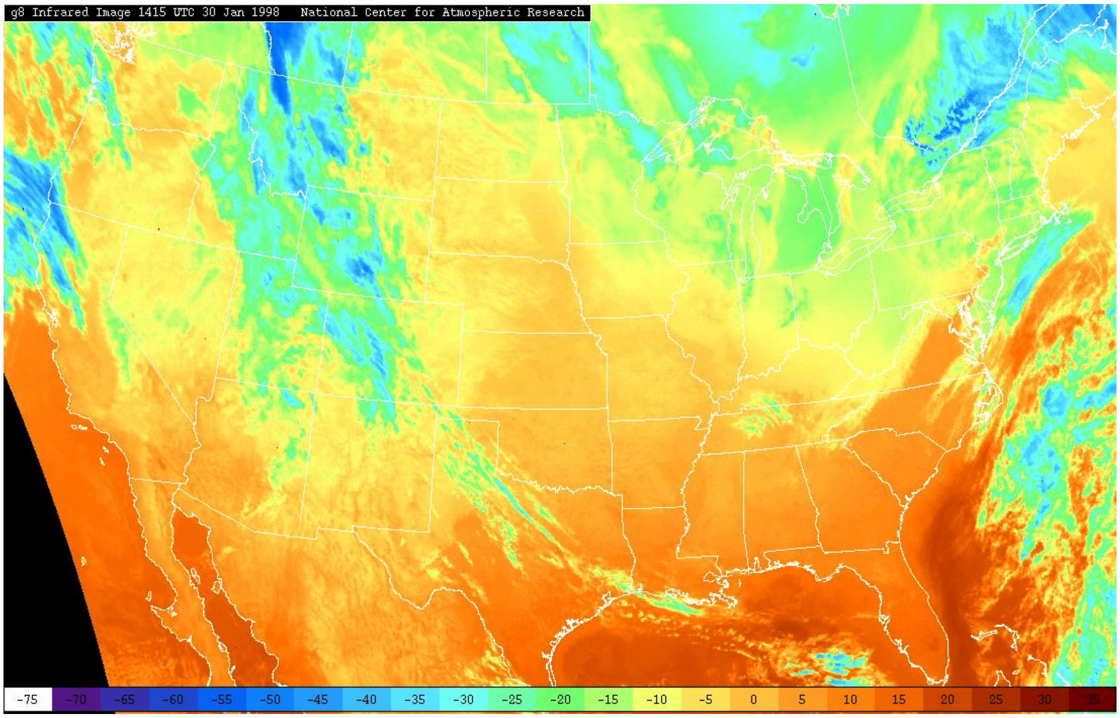


Figure 4 – GOES-8 a) infrared satellite image for 980130, 1215 UTC.



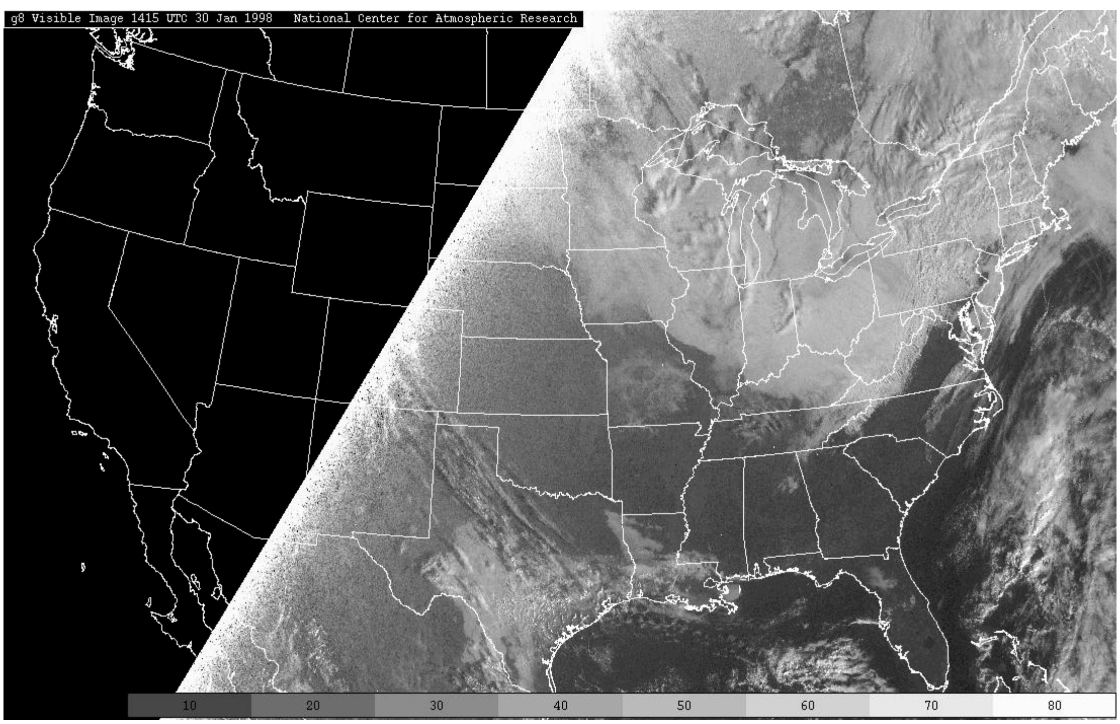
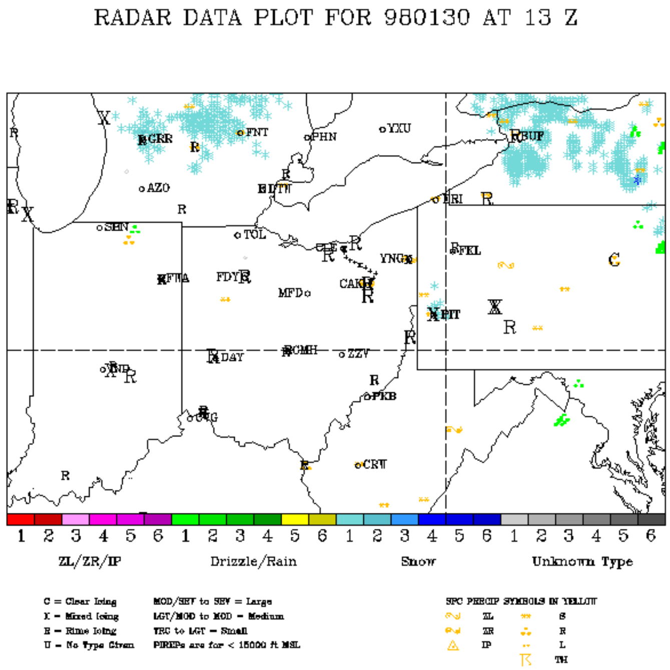


Figure 4 – GOES-8 b) infrared and c) visible satellite images for 980130, 1415 UTC.



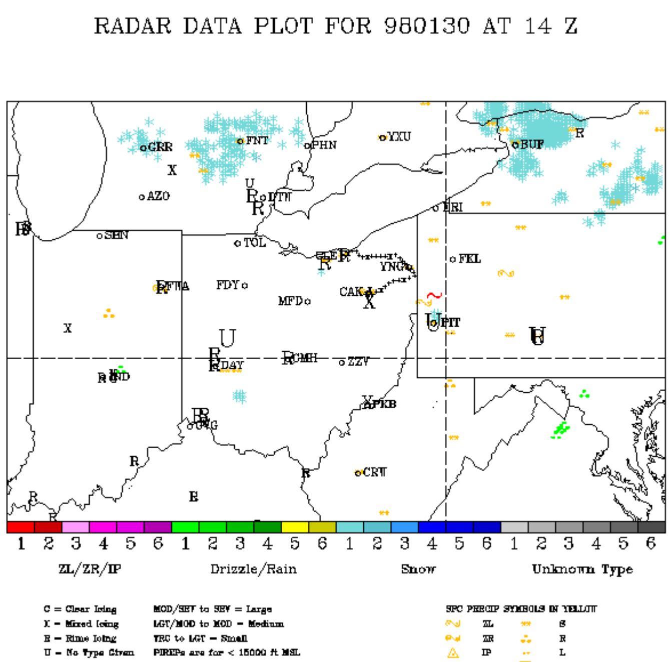
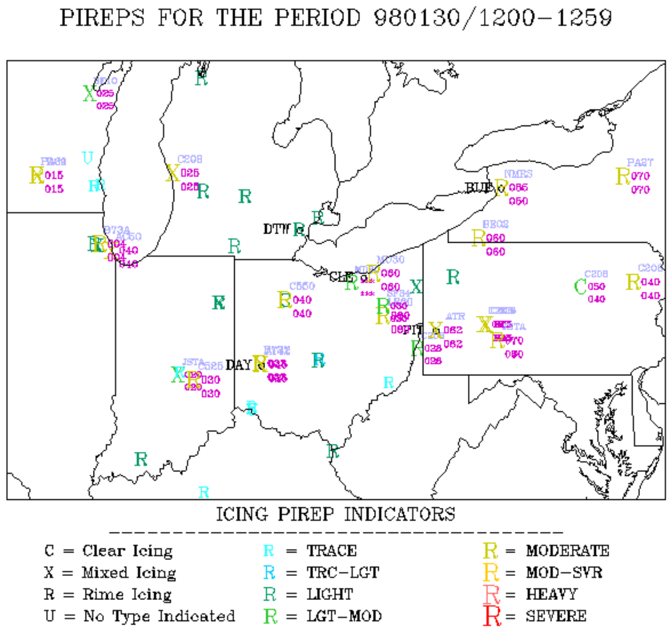


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980130, a) 1300 and b) 1400 UTC.



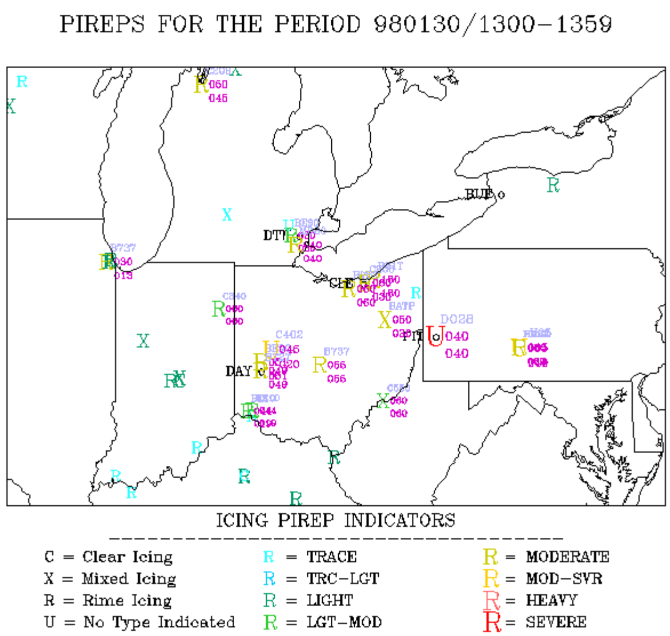


Figure 6 – Pilot reports of icing for 980130, a) 1200-1259 and b) 1300-1359 UTC.

February 4, 1998

Flight #1—From Cleveland, OH, to Parkersbug, WV, from 1441 to 1654 UTC.
Flight #2—Near Parkersburg, WV, from 1816 to 2028 UTC.
Flight #3—From Parkersburg, WV to Cleveland, OH, from 2200 to 2355 UTC.

Brief overview

Three flights were made on this day through a deep, classical freezing rain event. During the first flight, the Twin Otter searched for potential pockets of icing above the highest freezing level to the south of Cleveland (CLE), but only snow and very little liquid water was found there. The aircraft then descended into and examined the freezing rain layer below 4000 feet over southeast Ohio and near Parkersburg, West Virginia (PKB). Freezing rain was sampled both just above and below cloud base to the northwest of PKB. The second flight entailed northwest-southeast transects within the freezing rain layer (at 3000 feet) between southeast of PKB and Zanesville, Ohio (ZZV). Some sampling of the vertical structure of the melting zone was also performed near PKB. The classical freezing rain structure was clearly present, with aggregates of snow aloft, followed by melting snow and rain in the melting zone, and freezing rain in the subfreezing layer below. The King probe indicated LWC values as high as 0.25 at times in locations with freezing rain above cloud base, but its poor response to larger droplets is likely to have resulted in an underestimate of the actual LWC there. The third flight was made to sample the continuity of the classical freezing rain structure between PKB and CLE by performing a series of aircraft soundings from the surface to above the upper freezing level (6-7000 feet) at PKB, ZZV, CAK (Canton-Akron), and CLE. CAK was at the northern end of the freezing rain, but intermittent small-drop icing clouds were found between CAK and CLE.

Relevant weather features

At 12 UTC on 4 February, a weak, closed low was present along the Alabama-Georgia border at 500 mb, with a trough running to the northwest (Fig. 1). Southeast winds, warm advection, and saturated conditions were present to the northeast of the trough. The saturated air and warm advection reached the southern 3/4 of Ohio, where temperatures were –17C, while rather dry air and northeast winds were present over Michigan. The low was much stronger at 700 millibars, and was centered over Georgia. To the north and east of the low, warm advection and saturated conditions covered the southeastern two-thirds of Ohio, and areas to the south and east. Temperatures were –5C or so in this area. The strong low was also evident over Georgia at 850 mb, with saturated conditions across the southern part of the forecast area, including all of Ohio and West Virginia. Warm advection covered much of the mid-Atlantic states and Appalachians, reaching as far west as the Ohio-West Virginia border, where the temperature was -2 C and winds were from the east. A cold pocket was present over Michigan, Indiana, and Illinois, where temperatures were colder than -5C, and winds were from the northeast. Dry air was present to the north of Ohio.

By 0 UTC, 5 February, the low strengthened at all levels and was positioned just off the South Carolina coast, while the trough axis remained in place to its northwest (Fig. 2). Saturated conditions, warm advection, and easterly flow continued across the forecast area at 500 and 700 mb. At 850 mb, a pocket of above freezing air wrapped in along the west side of the Appalachians on northeast winds. Colder air and weak cold advection were present along the Appalachians, just to the southeast of the warm pocket. Temperatures were approximately -4C along the eastern border of West Virginia.

Sounding data from 12 UTC from Pittsburgh (Fig. 3) essentially show a classical freezing rain temperature structure, though the temperature only reached a maximum of -1C at ~890 mb, then sharply cooled to -5C at ~910 mb. Winds shifted from easterly at ~25 knots above to northeasterly at ~30 knots below this transition, and deep saturated conditions were present. At 0 UTC, the freezing rain structure was more clearly present at Pittsburgh, as the sounding was slightly warmer, with T = + 1C at 875 millibars, and T = -2C at 925 mb. The 12 UTC Wilmington, Ohio sounding also had deep saturation, a sharp wind shift, and increasing temperature from 900 to 825 mb. However, the maximum temperature was only -2C, so no melting was occurring, and thus, the precipitation was snow there. By 0 UTC, the maximum temperature reached 0C at 840 mb. These changes in the sounding structures across the region match the spotty freezing rain, ice pellets, and rain early in the day near Pittsburgh and in West Virginia which spread into western Ohio by 00 UTC. An NCAR CLASS sounding launched from Cleveland at 1920 UTC also had the classical freezing rain temperature structure, but relatively dry air was present from ~700 mb down to the top of the transition zone, preventing precipitation from occurring there.

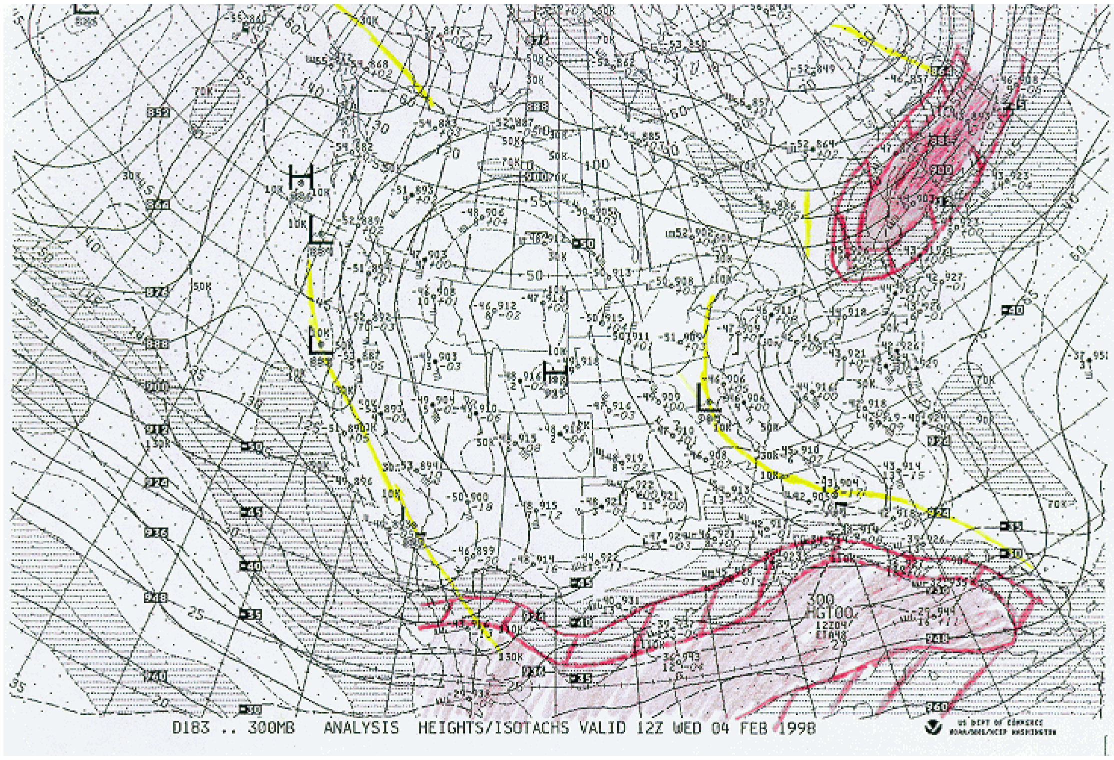
The surface map for 12 UTC (Fig. 4) showed a 1028 mb high pressure area sprawled the across the northern Great Lakes, while a strong, 986 mb low was centered along the Georgia/South Carolina border. In between, a strong pressure gradient and northeast to north winds were present across the forecast area. A warm front was indicated along the North Carolina coast, while a dissipating cold front draped from west to east across Virginia. A swath of light and moderate rain was present along the east slope of the Appalachians from Georgia to Virginia, while snow was occurring across and on the west side of the Appalachians. Spotty observations of ice pellets were made along the rain-snow boundary, indicating the early presence of the classical freezing rain structure, as seen in the sounding data. By 15 UTC, ice pellets, freezing rain, and rain were occurring along the West Virginia borders with Ohio, Kentucky, and Pennsylvania, while snow extended as far north as Zanesville, and overcast conditions were present to the north, including over Cleveland. At 18 UTC, the ice pellets, freezing rain, and rain area developed into a pocket centered nearer Parkersburg, and were surrounded by snow, even to the east (eastern West Virginia). This continued at 21 UTC, then the freezing rain began to spread westward and northward across Ohio and Pennsylvania by 00 UTC. During the period from 12 UTC to 00 UTC, the surface low tracked slowly northeast along the Carolina coast, while the high pressure area to the northwest remained nearly stationary.

Regional radar data (Fig. 5) showed precipitation and a mixture of precipitation types across southern Pennsylvania, West Virginia, southwestern Ohio, and Kentucky. The Twin Otter flew south-southwest past Columbus by ~1545 UTC, entering areas of snow on the northwestern edge of the precipitation shield, then turned east toward Parkersburg, entering the area with rain at the surface, and

freezing rain aloft. Radar echoes from the mixed rain, freezing rain, and ice pellets were relatively intense in a southwest to northeast line across the Parkersburg area. This is likely to have been due the occurrence of ice pellets and large rain drops there, since the melting zone was above 3000 feet. The northern edge of the radar echo gradually crept northward to Canton-Akron and Mansfield by 19 UTC and remained near those locations through 22 UTC. This northern edge nicely matched the northern extent of a the precipitation particles encountered aloft on the return flight to Cleveland.

Infrared and visible satellite imagery from 12 to 22 UTC (Fig. 6) indicated deep, cold cloud, with CTTs of less than -40C, over most of the forecast area. Such cold CTTs match the efficient formation of precipitation there, while breaks in the clouds and pockets of warm CTTs match the dry air aloft and lack of precipitation over Michigan. An intrusion of upper level dry air that moved northwest into West Virginia is evident on the infrared plots (also as of break in the radar echo), but this did not reach Parkersburg until the aircraft sampling in this area had been completed. One pocket of warm CTTs (> -15C) became evident over Cleveland and Mansfield at 2215 UTC, and may have helped to end the snow at Mansfield after 22 Z, as well as allow the low-level, patchy cloud to exist north of Canton-Akron (sampled at the end of flight 3).

Moderate or greater PIREPs were found primarily in two altitude ranges (Fig. 7). Between 2,500 and 4,000 feet, moderate and even severe, mostly mixed and clear PIREPs were indicated in the freezing rain layer across West Virginia and southeastern Ohio. A couple of moderate rime PIREPs over northwestern Ohio were also present in some thinner, lower cloud decks. Other moderate rime PIREPs occurred between 11,000 and 14,000 feet, mostly over northern Kentucky and central Ohio (late) in pockets of warmer CTTs. Twin Otter flights at these altitudes were in areas of colder CTTs, and thus, mostly snow, and little LWC was found there.



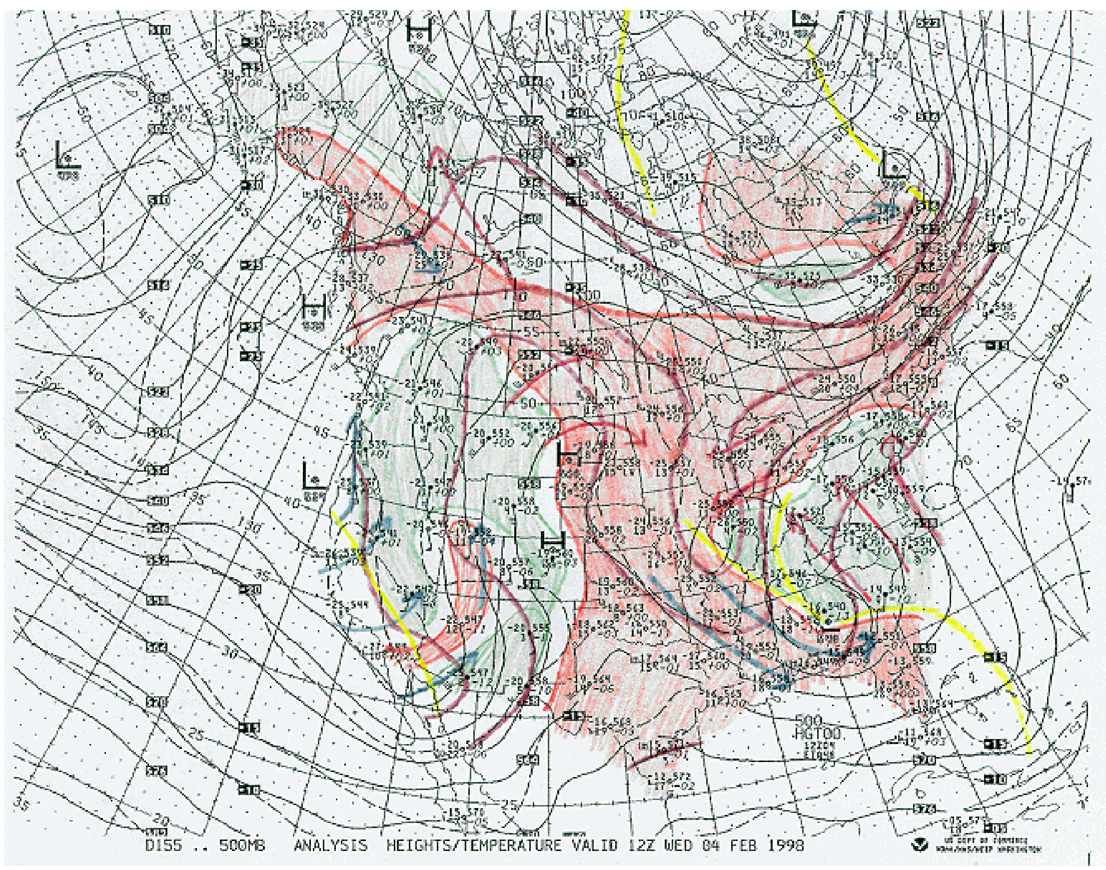


Figure 1 – Upper-air charts for 980204, 1200 UTC at a) 300 and b) 500 mb.

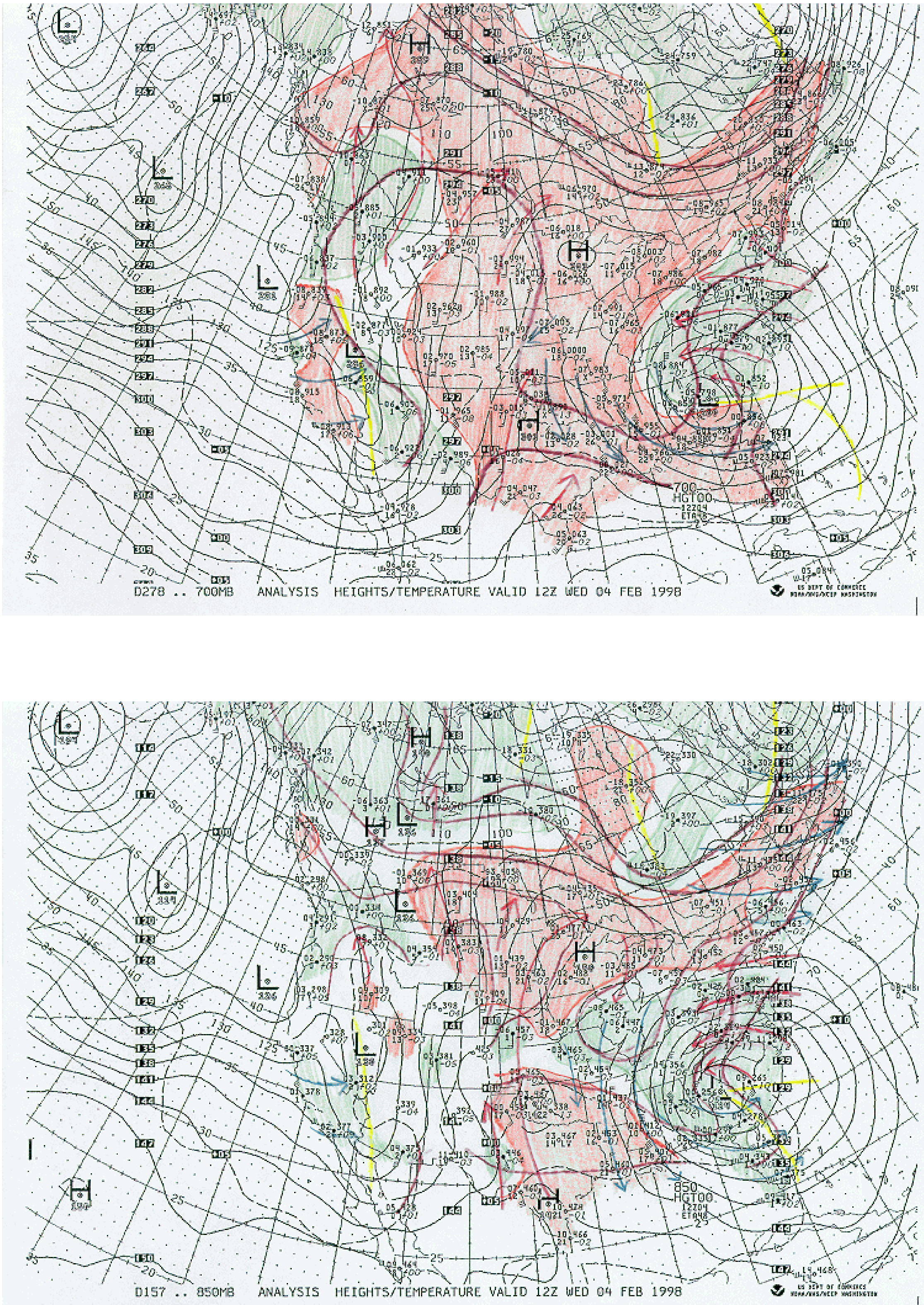
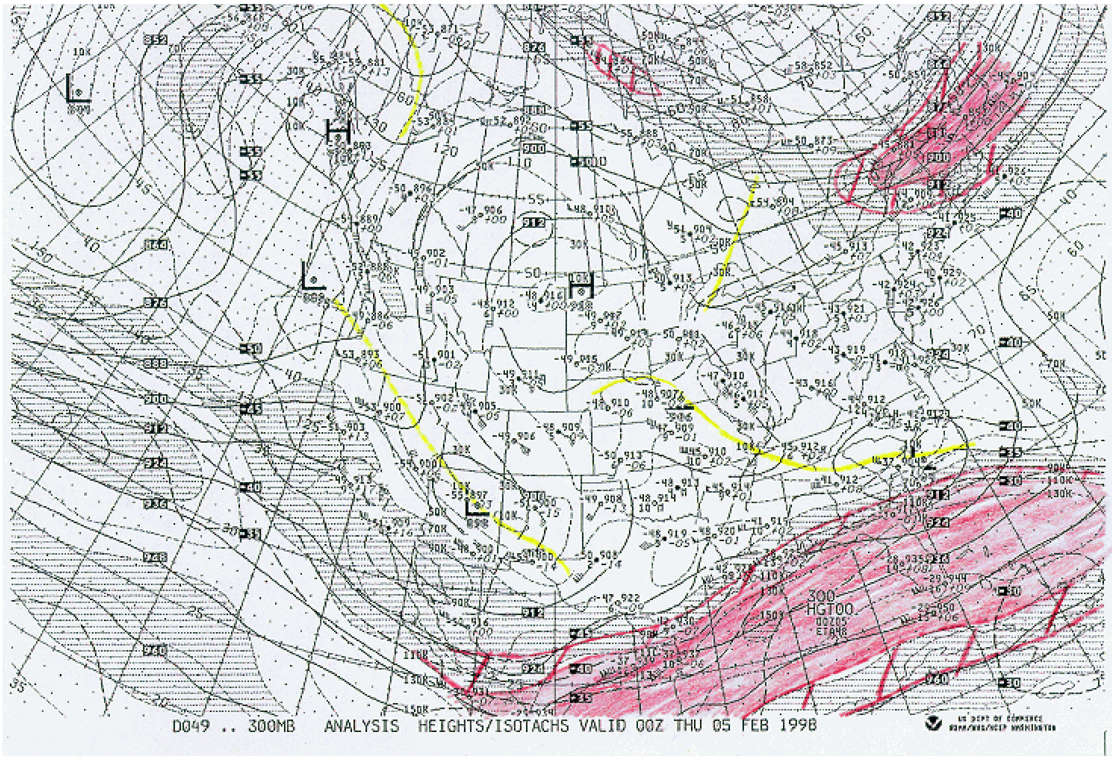


Figure 1 – Upper-air charts for 980204, 1200 UTC at c) 700 and d) 850 mb.



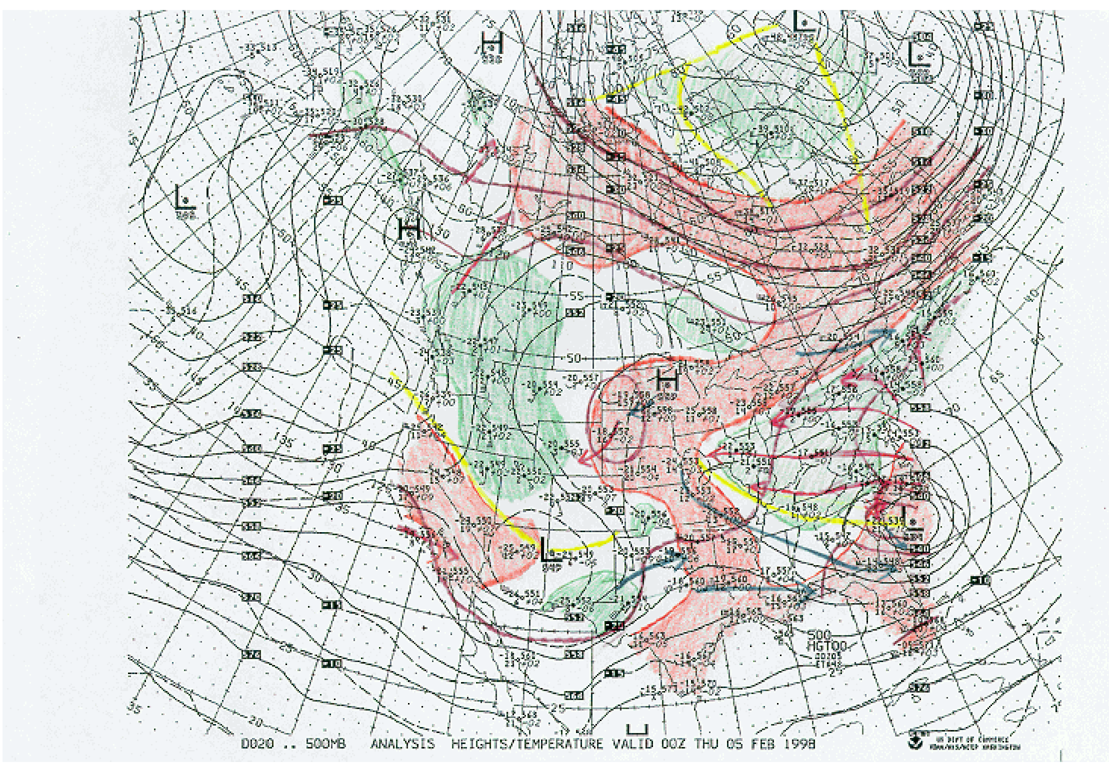
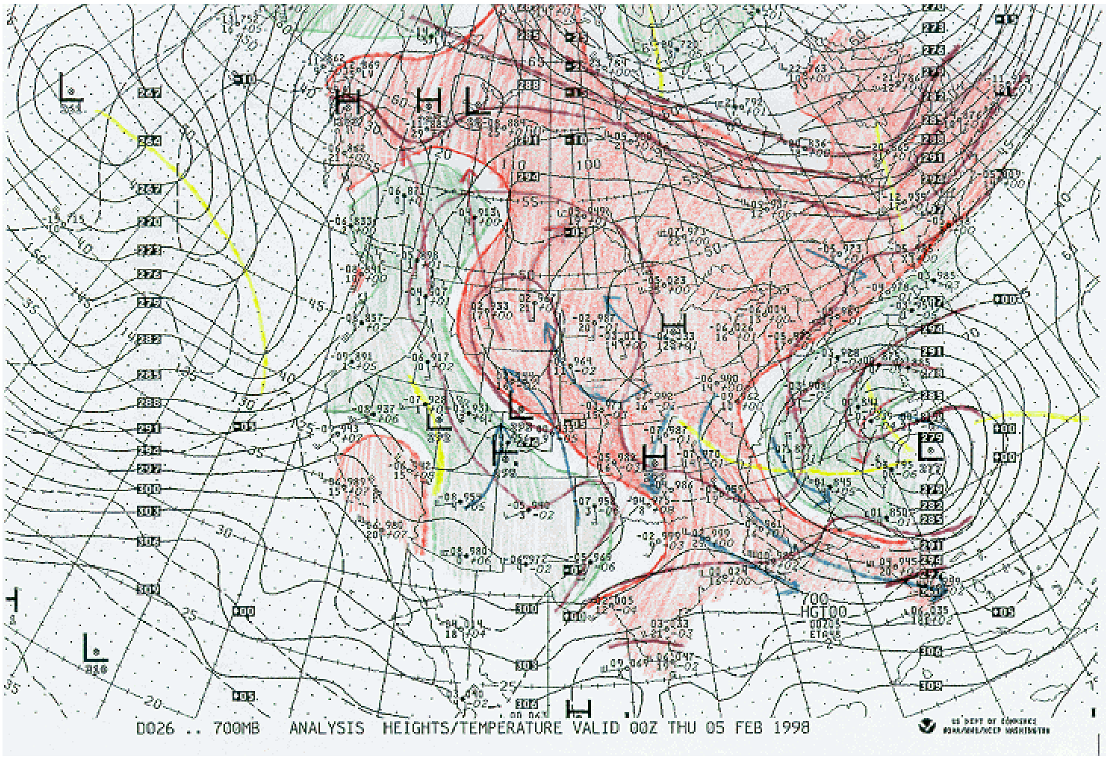


Figure 2 – Upper-air charts for 980205, 0000 UTC at a) 300 and b) 500 mb.



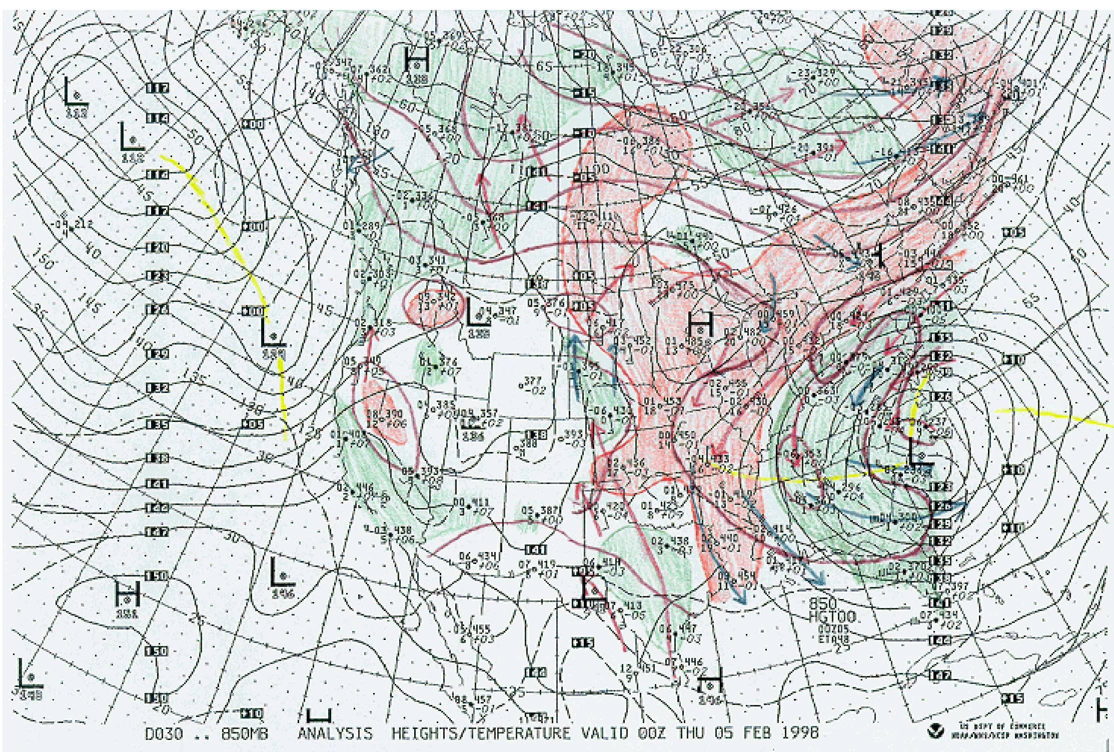
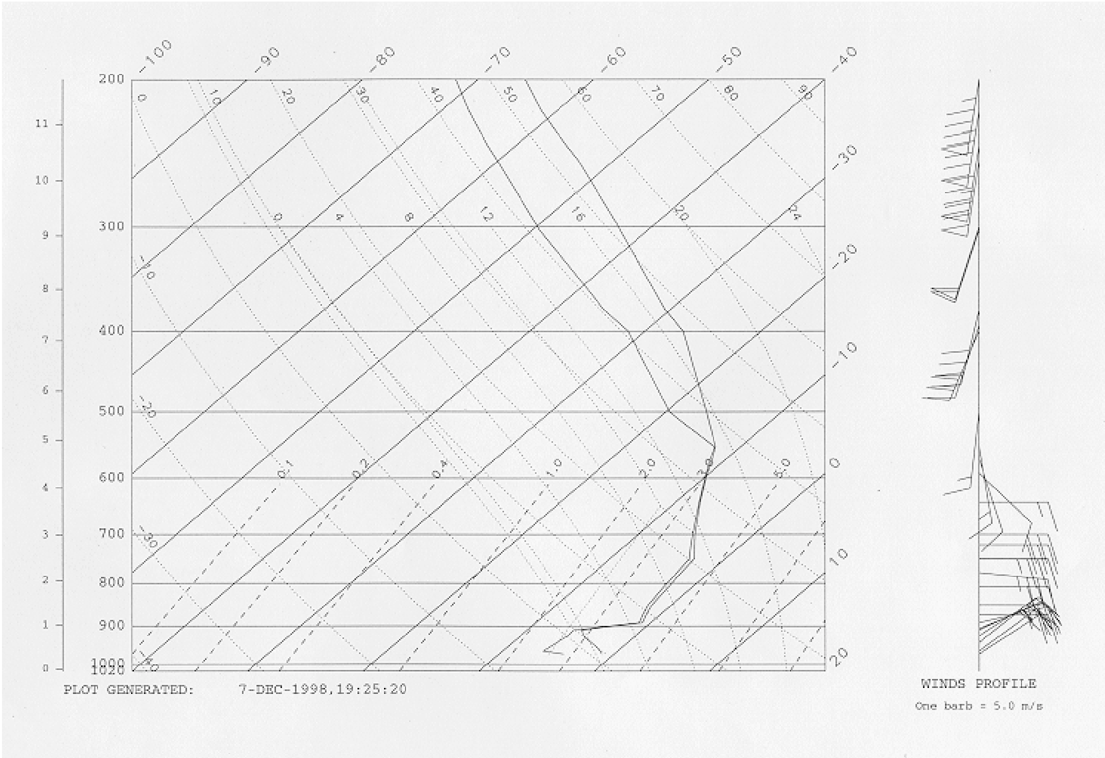


Figure 2 – Upper-air charts for 980205, 0000 UTC at c) 700 and d) 850 mb.



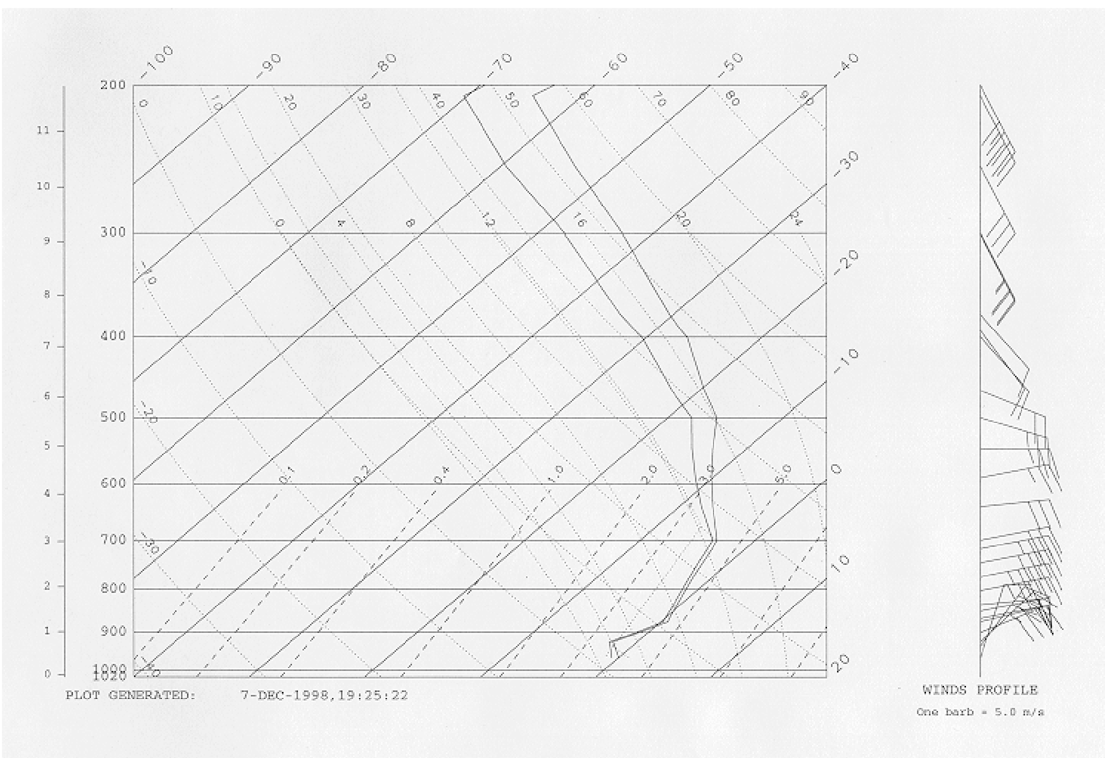


Figure 3 – Balloon-borne soundings from Pittsburgh at a) 980204, 1200 and b) 980205, 0000 UTC.

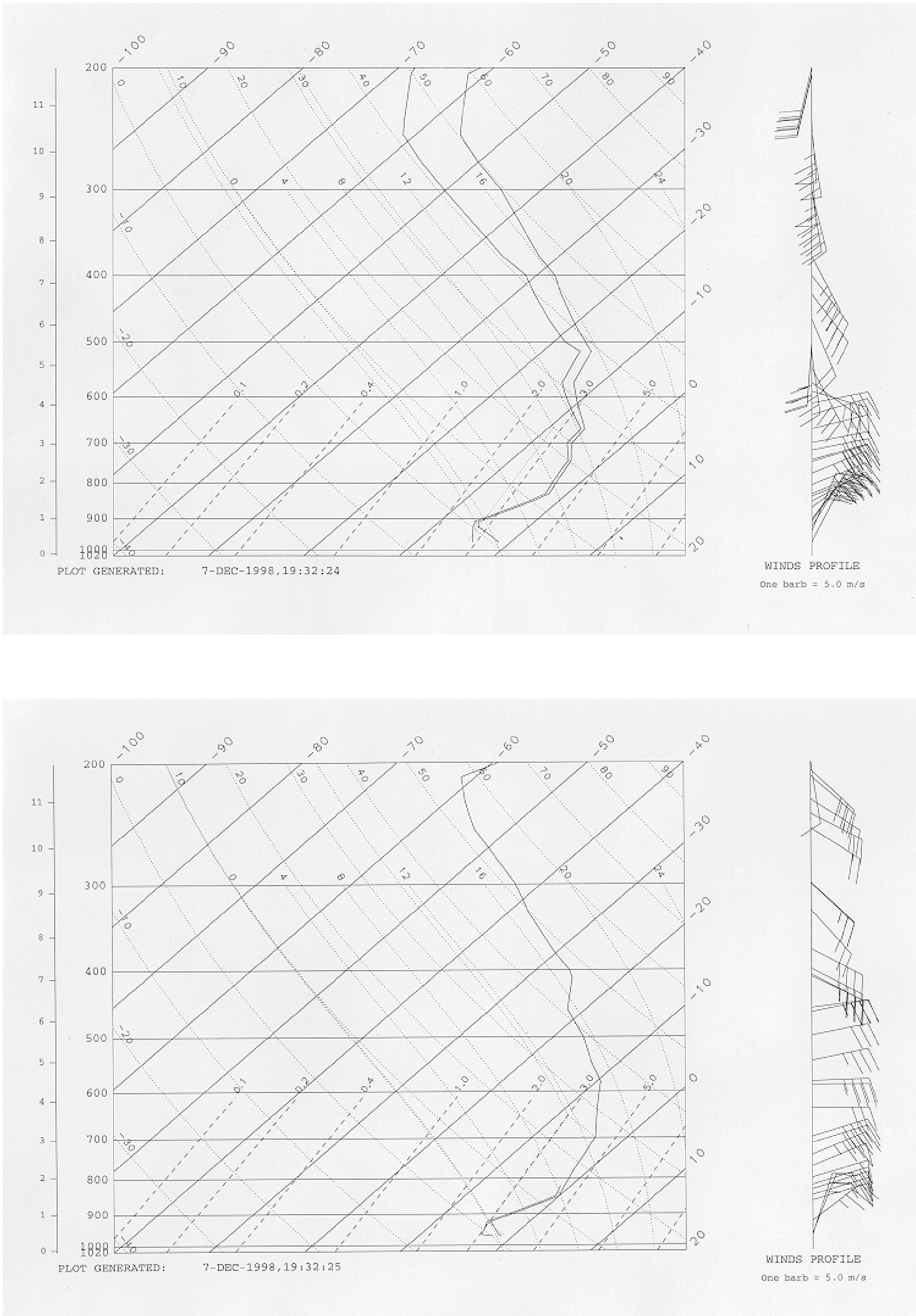
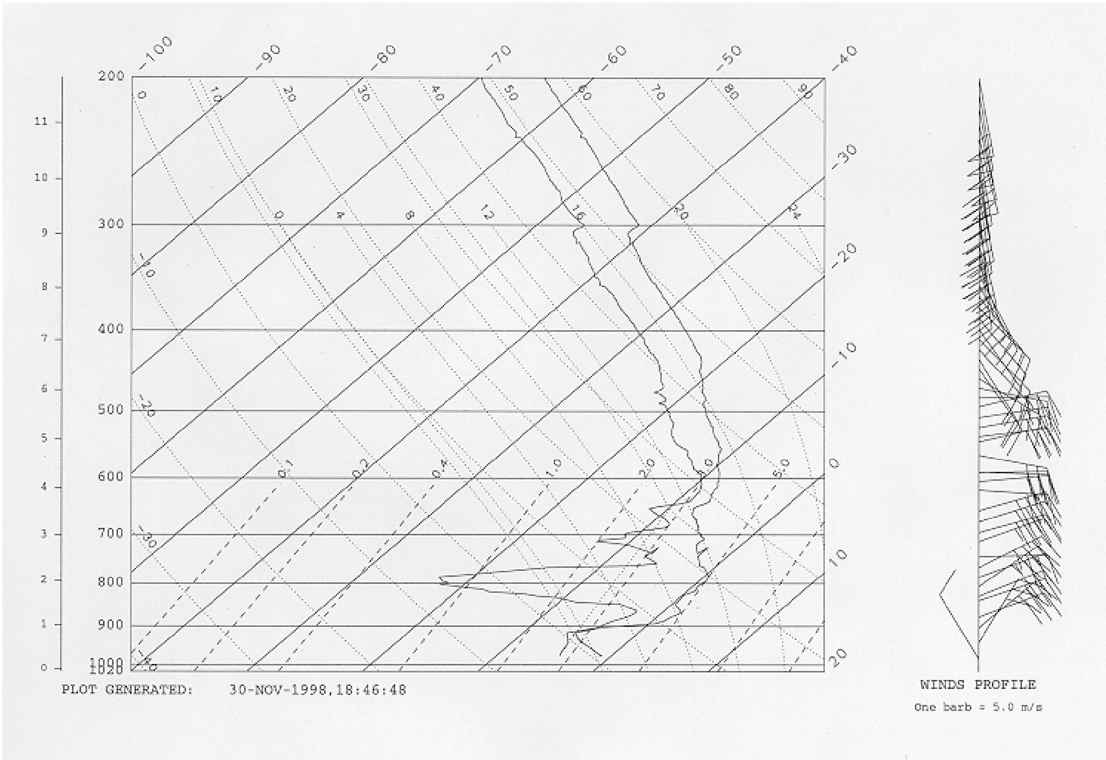


Figure 3 – Balloon-borne soundings from Wilmington at c) 980204, 1200 and d) 980205, 0000 UTC.



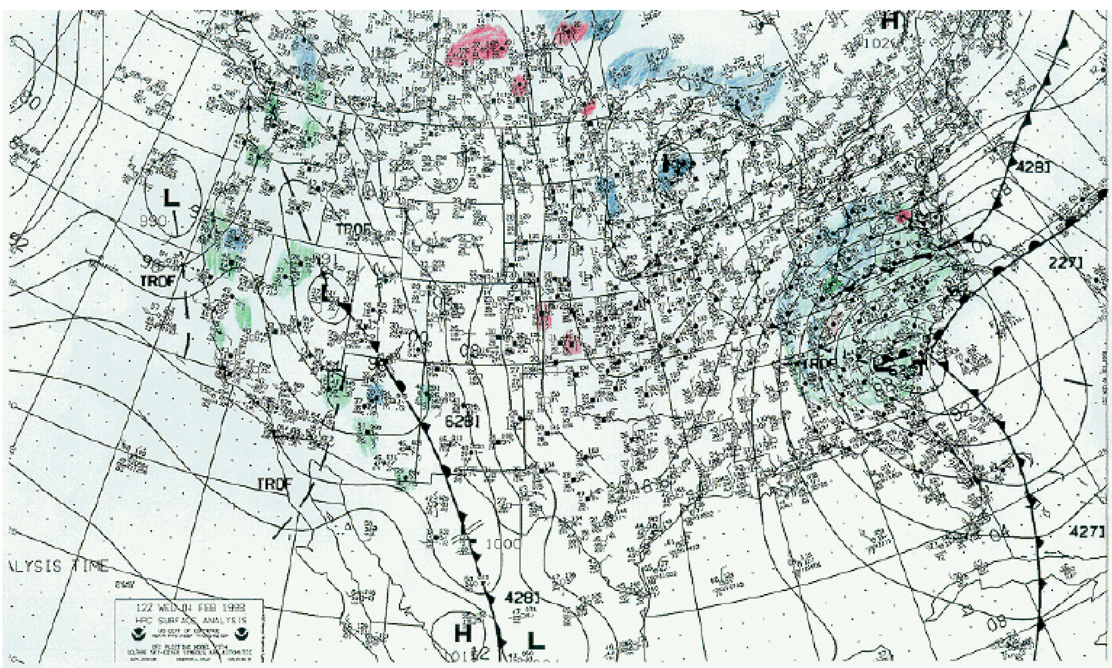
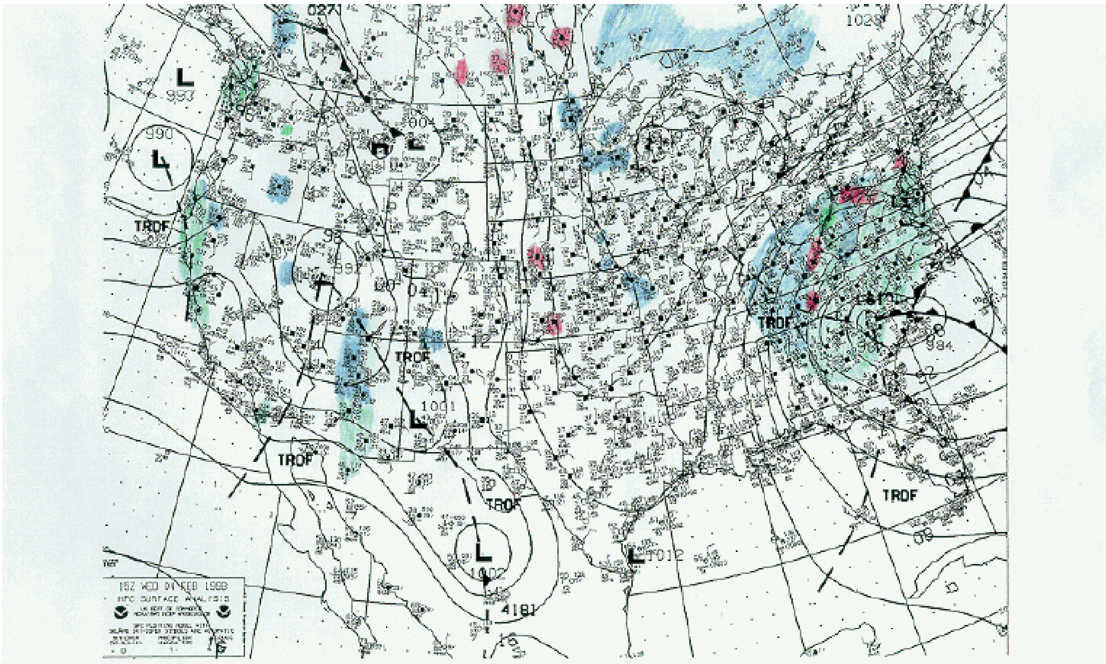


Figure 3 – Balloon-borne soundings from Cleveland at e) 980204, 1920 UTC.

Figure 4 – Surface chart for a) 980204, 1200 UTC.



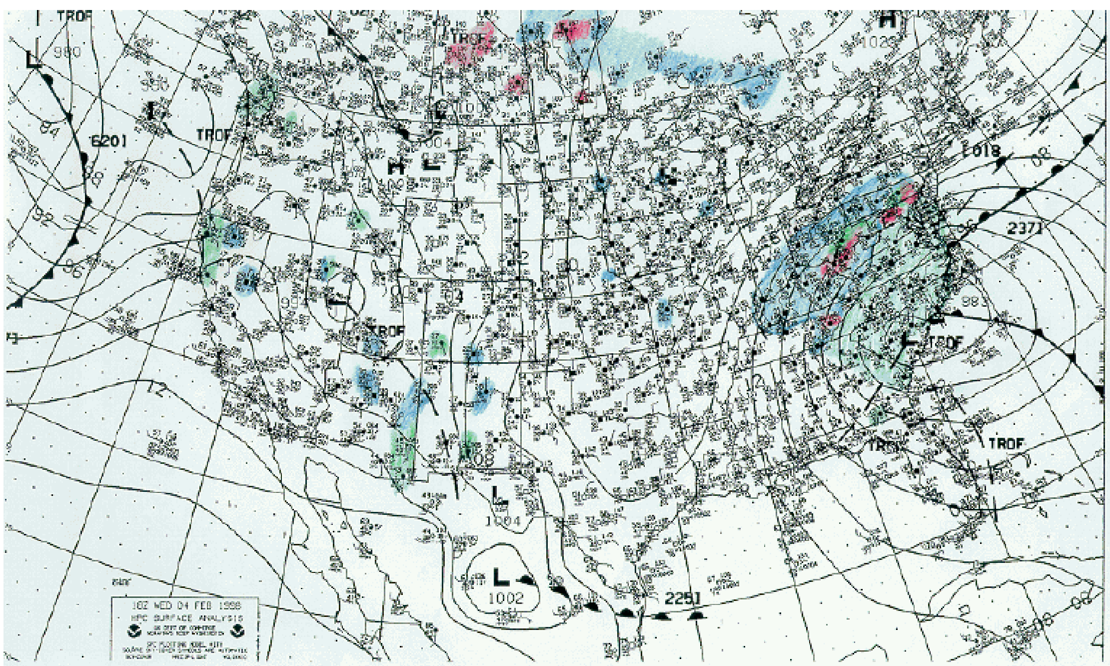
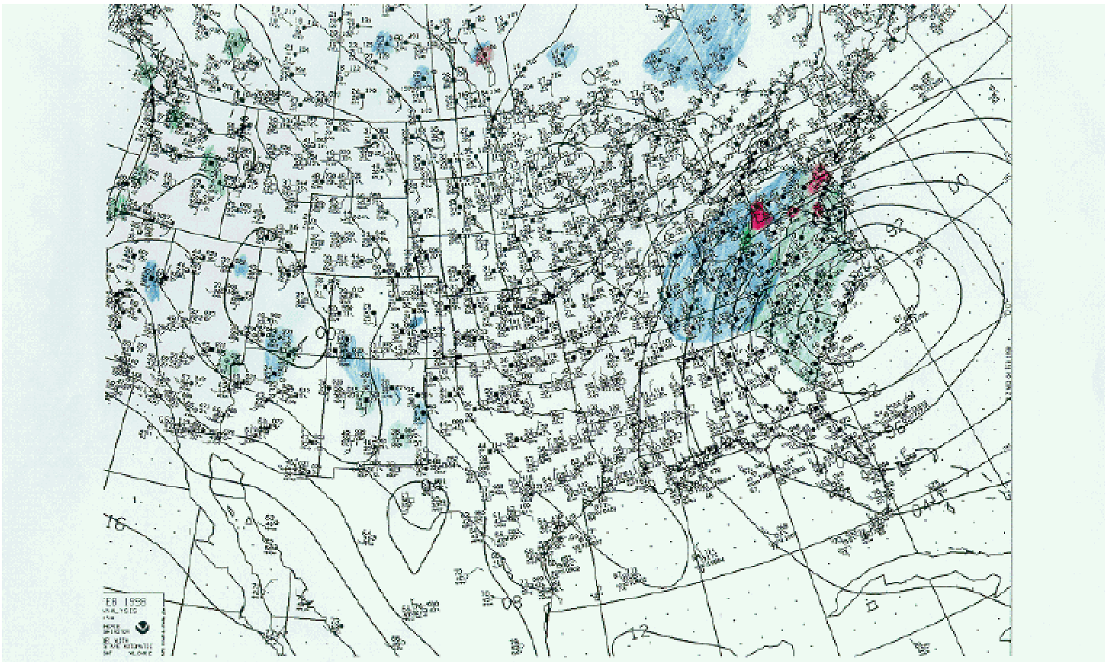


Figure 4 – Surface charts for 980204, b) 1500 and c) 1800 UTC.



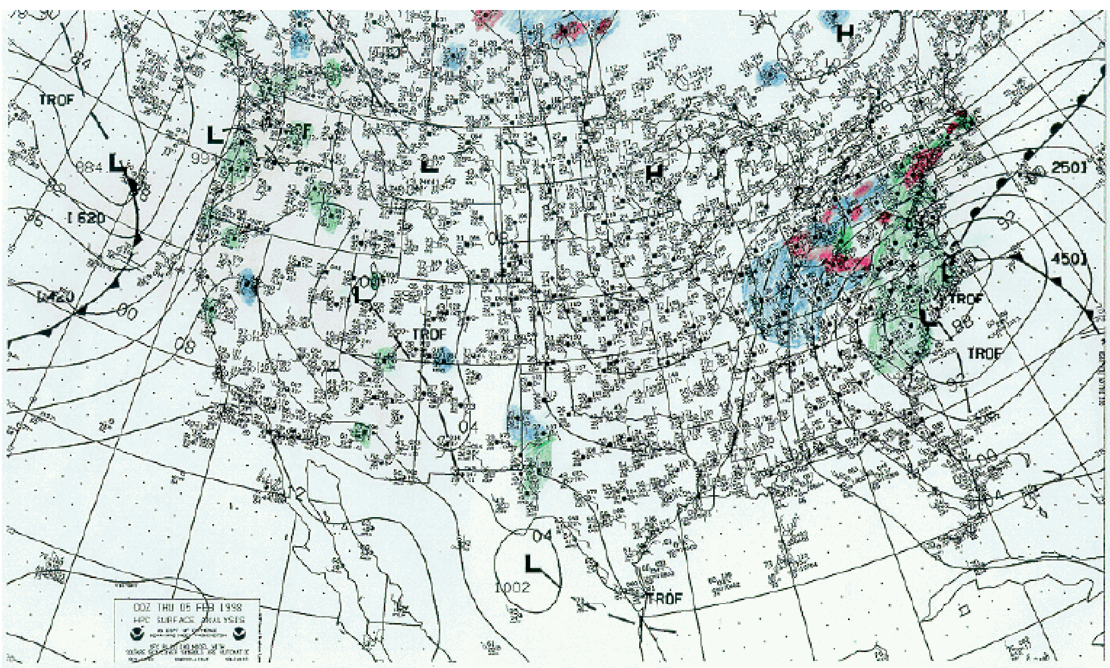
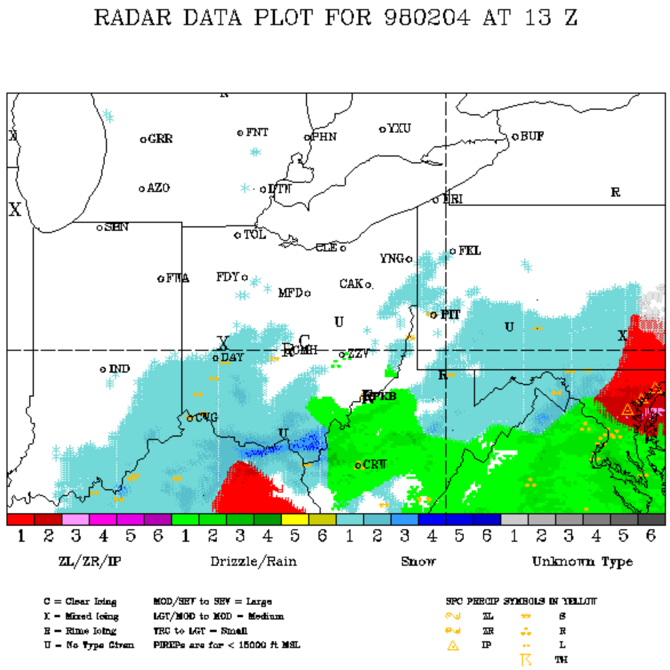


Figure 4 – Surface charts for d) 980204, 2100 and e) 980205, 0000 UTC.



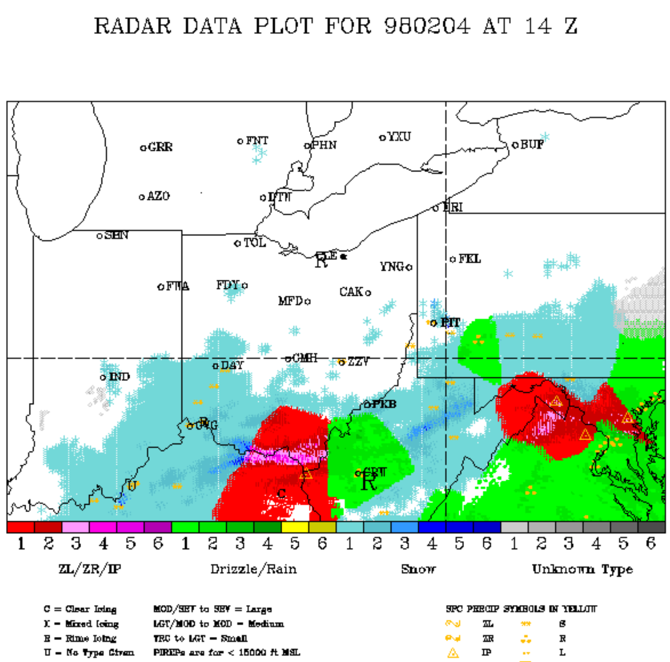
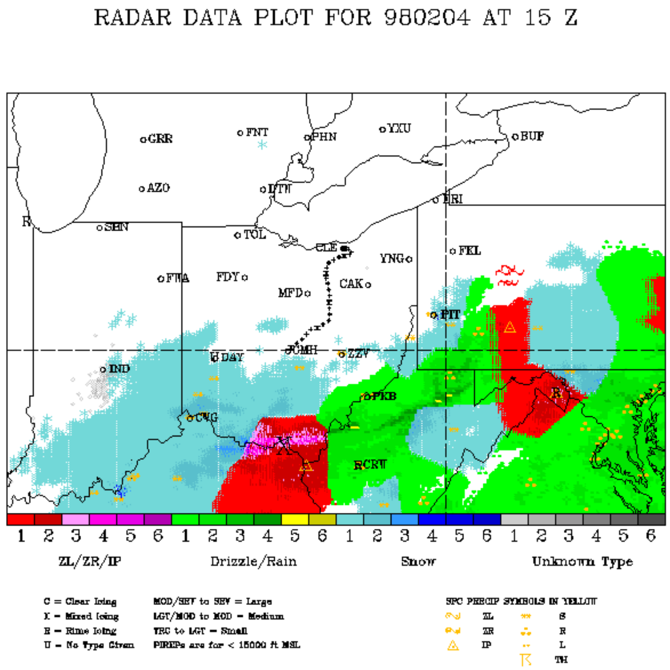


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980204, a) 1300 and b) 1400 UTC.



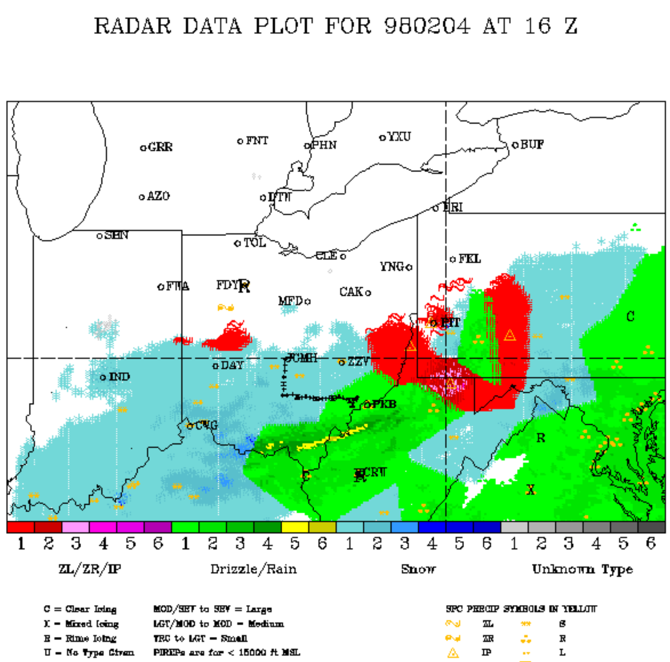
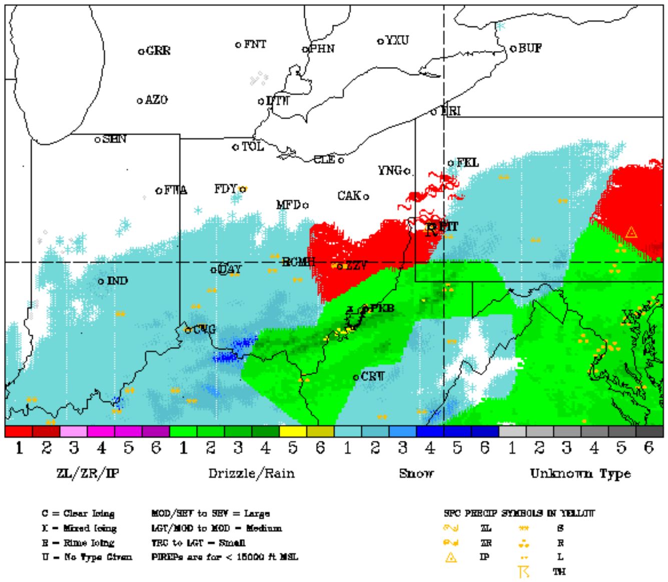


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980204, c) 1500 and d) 1600 UTC.

RADAR DATA PLOT FOR 980204 AT 17 Z



RADAR DATA PLOT FOR 980204 AT 18 Z

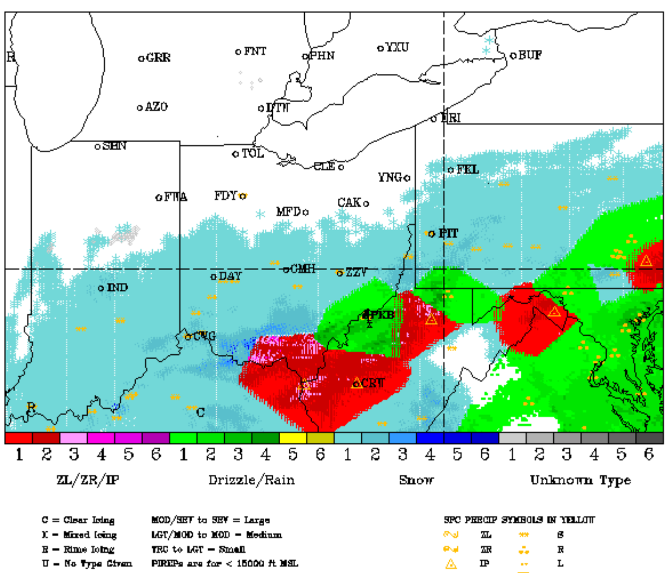
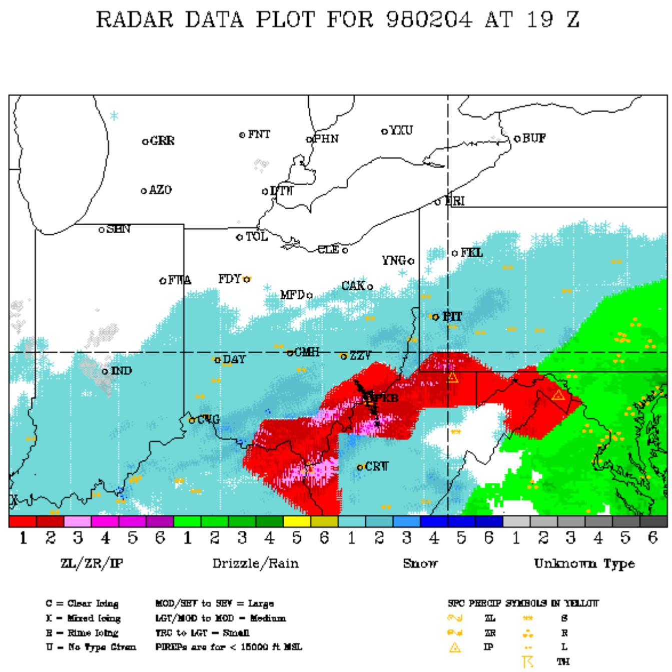


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980204, e) 1700 and f) 1800 UTC.



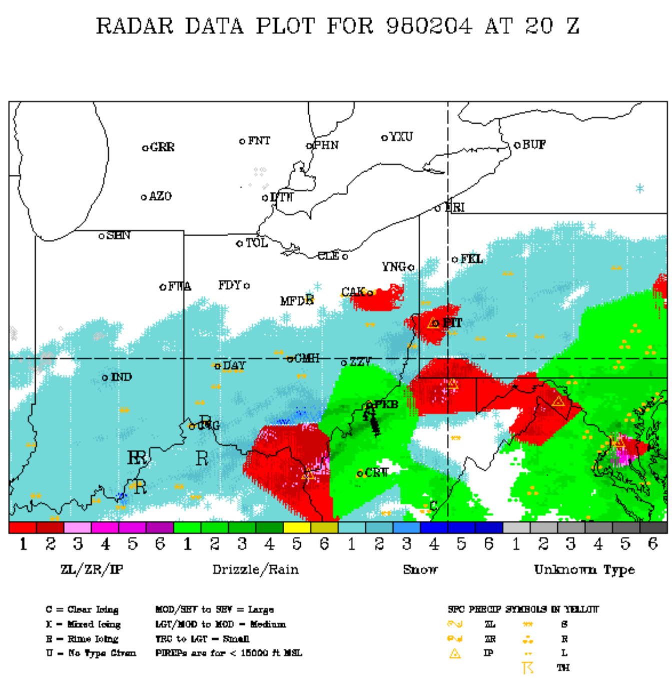
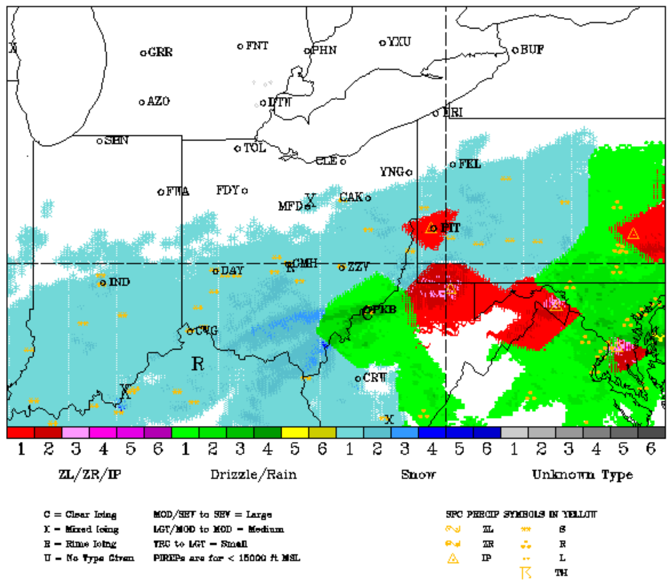


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980204, g) 1900 and h) 2000 UTC.

RADAR DATA PLOT FOR 980204 AT 21 Z



RADAR DATA PLOT FOR 980204 AT 22 Z

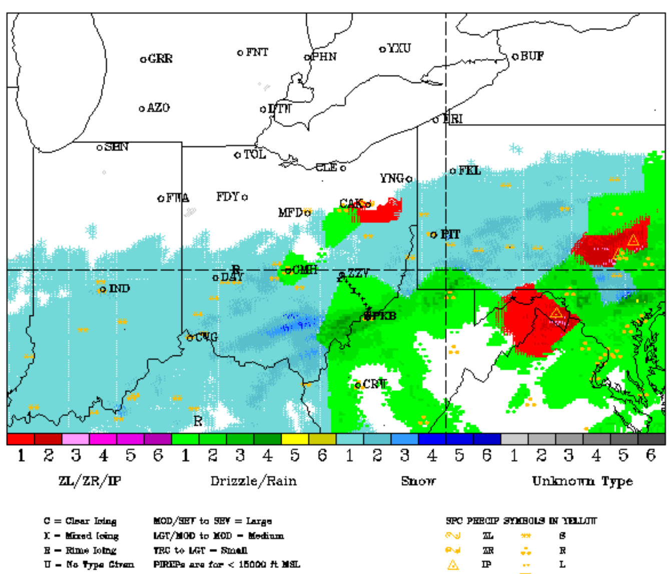
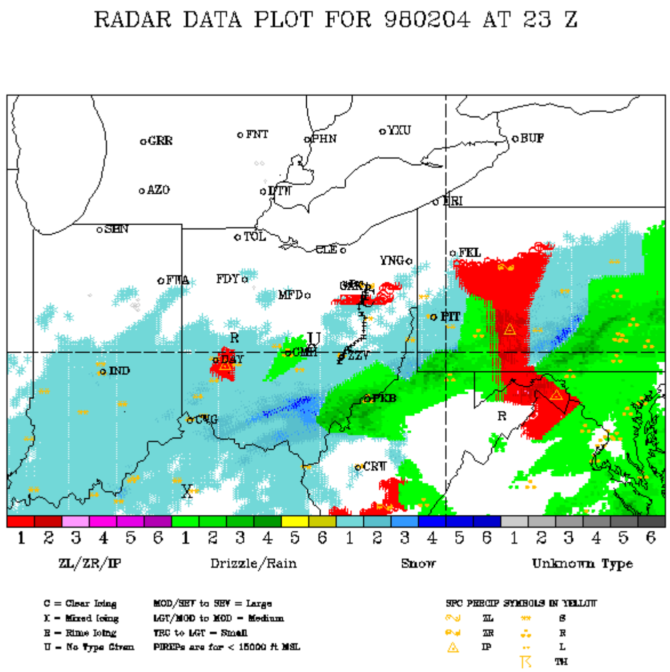


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980204, i) 2100 and j) 2200 UTC.



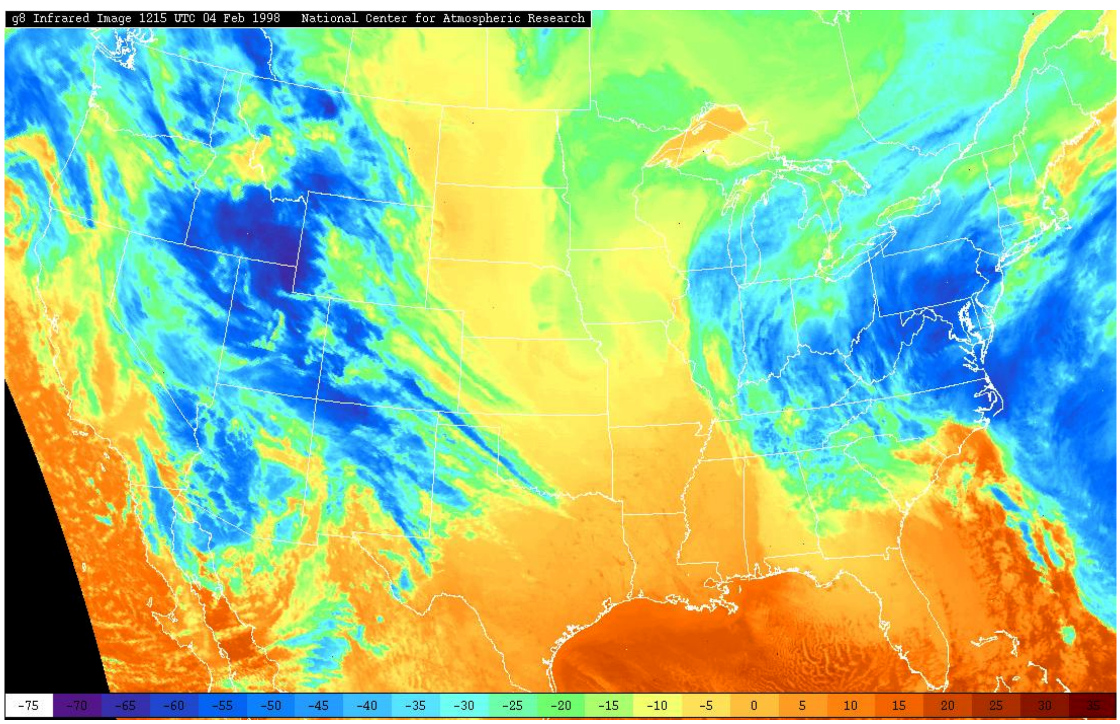
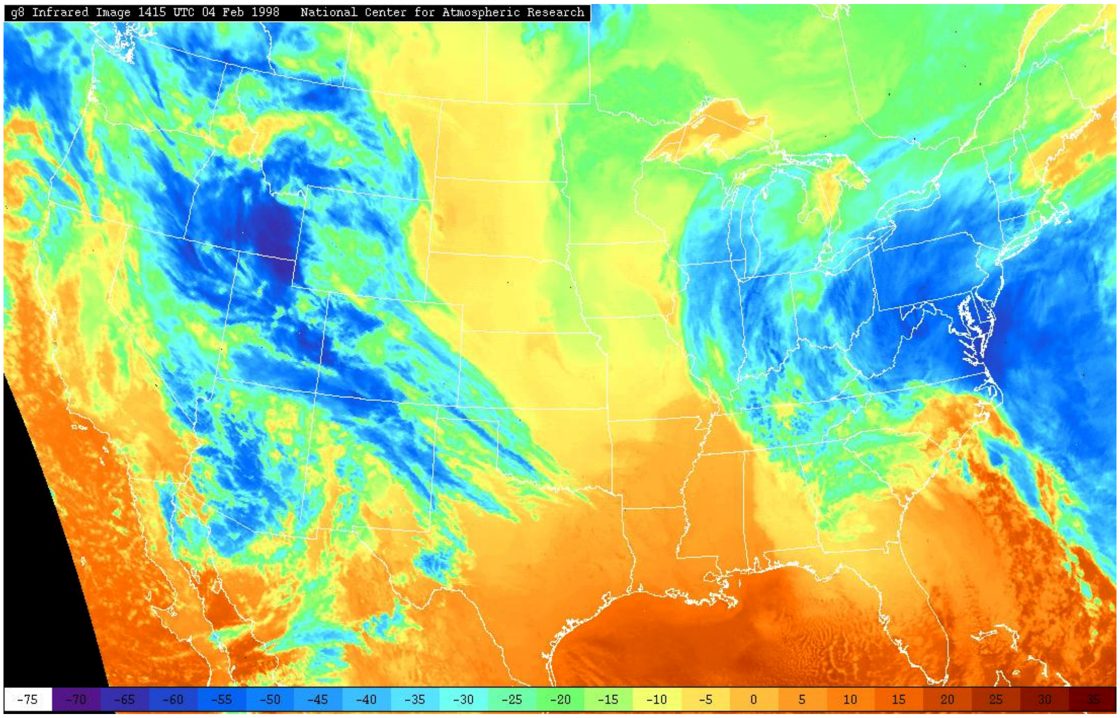


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for k) 980204, 2300 UTC.

Figure 6 – GOES-8 infrared satellite image for a) 980204, 1215 UTC.



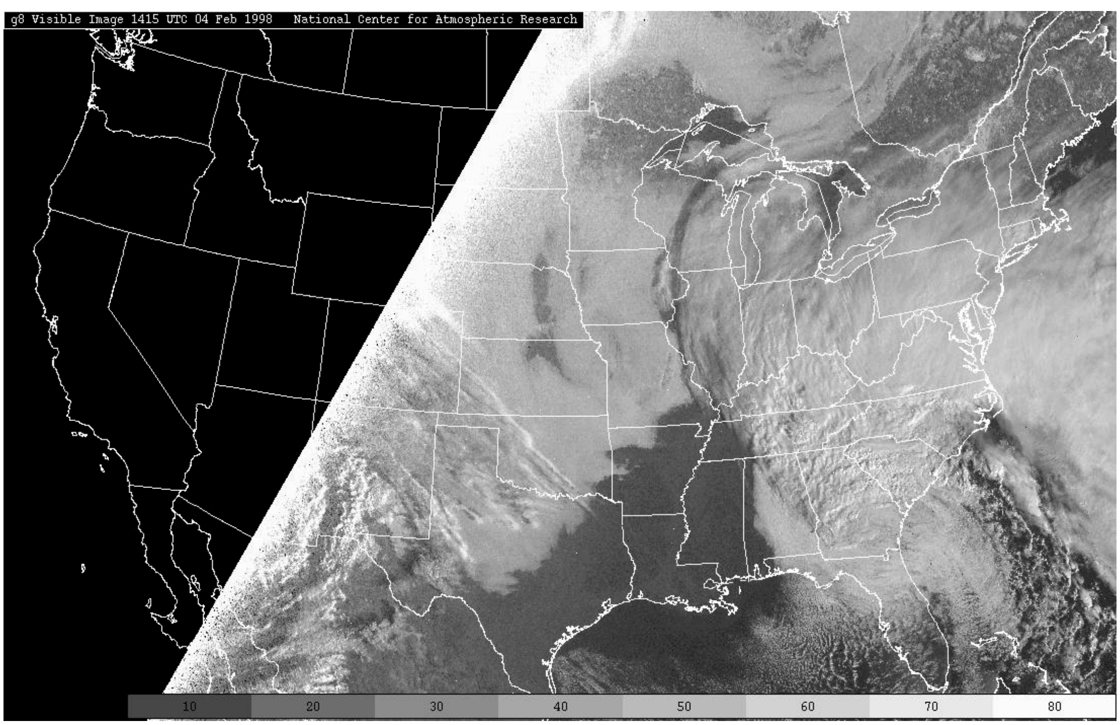
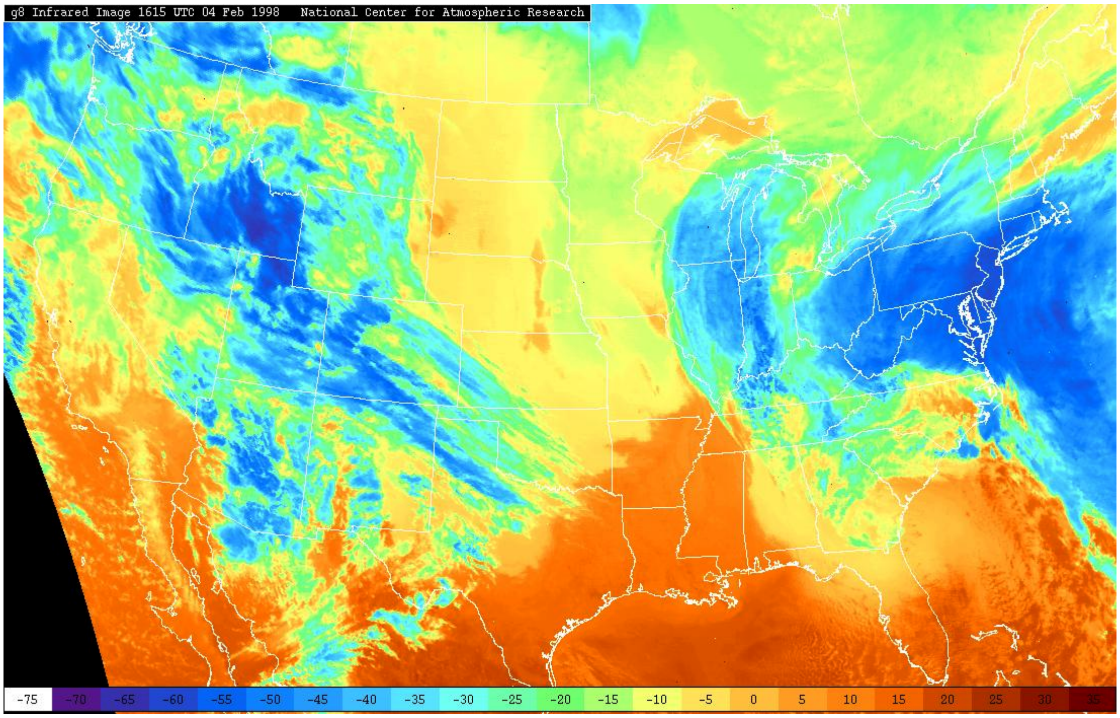


Figure 6 – GOES-8 b) infrared and c) visible satellite images for 980204, 1415 UTC.



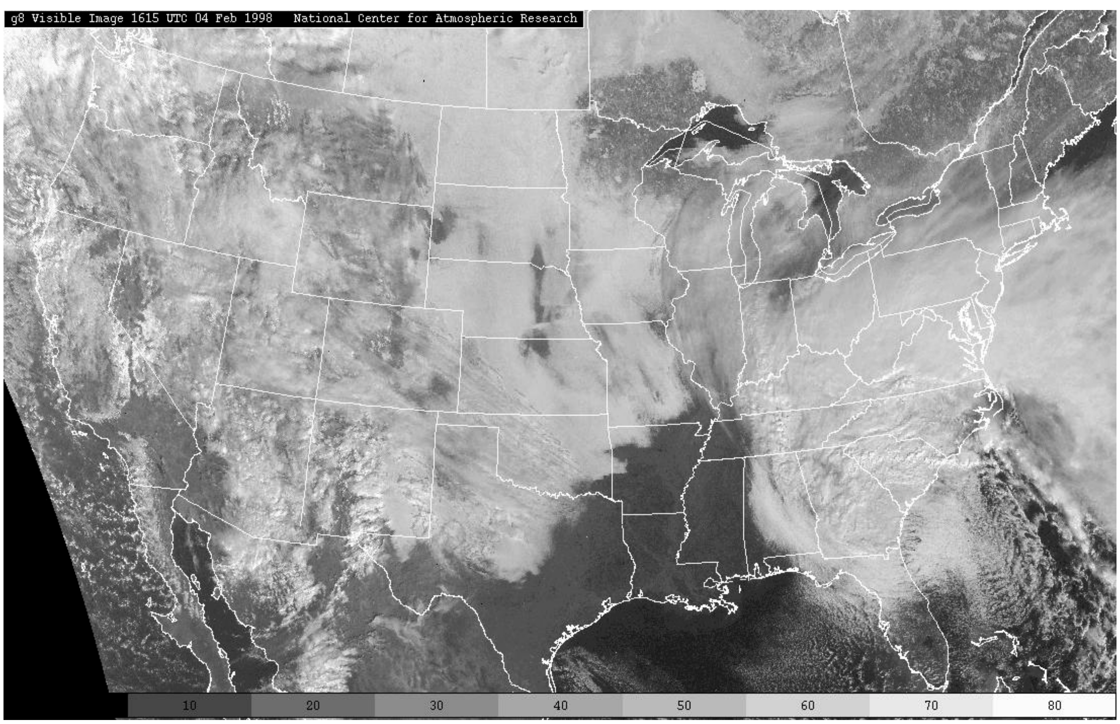
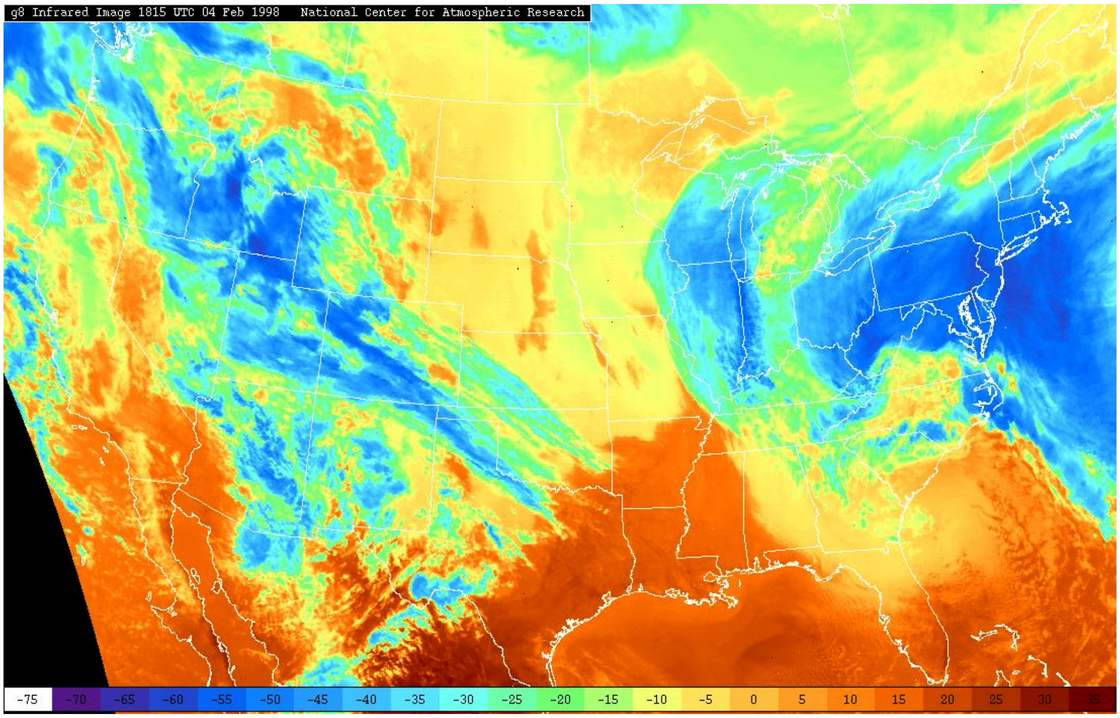


Figure 6 – GOES-8 d) infrared and e) visible satellite images for 980204, 1615 UTC.



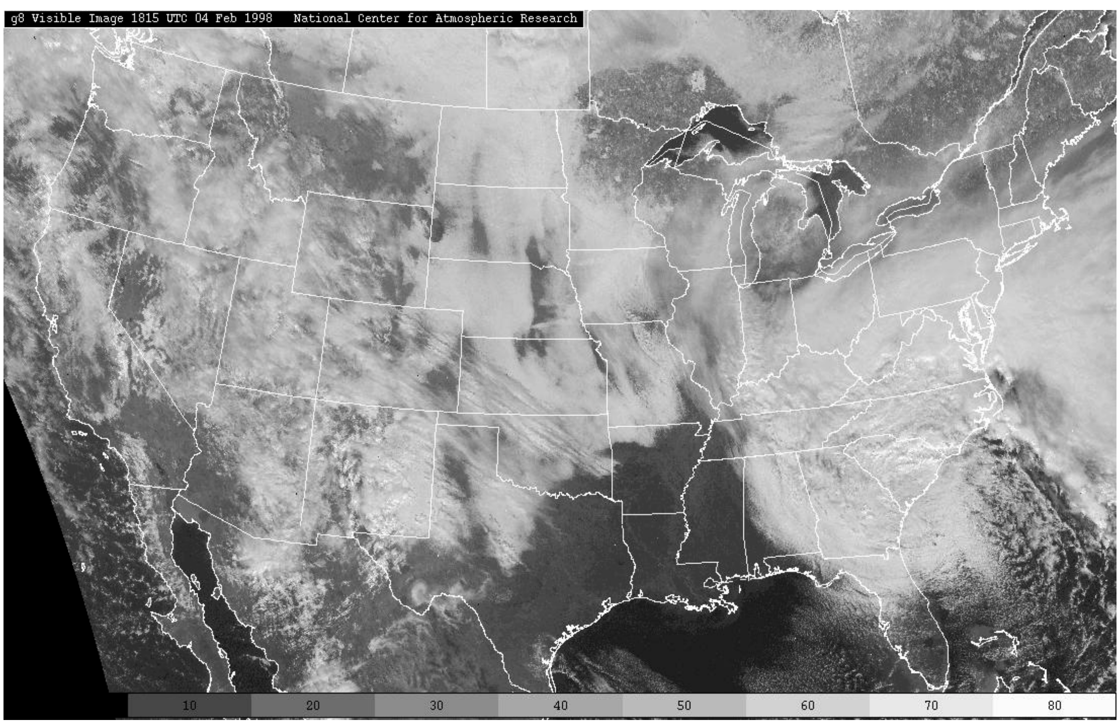
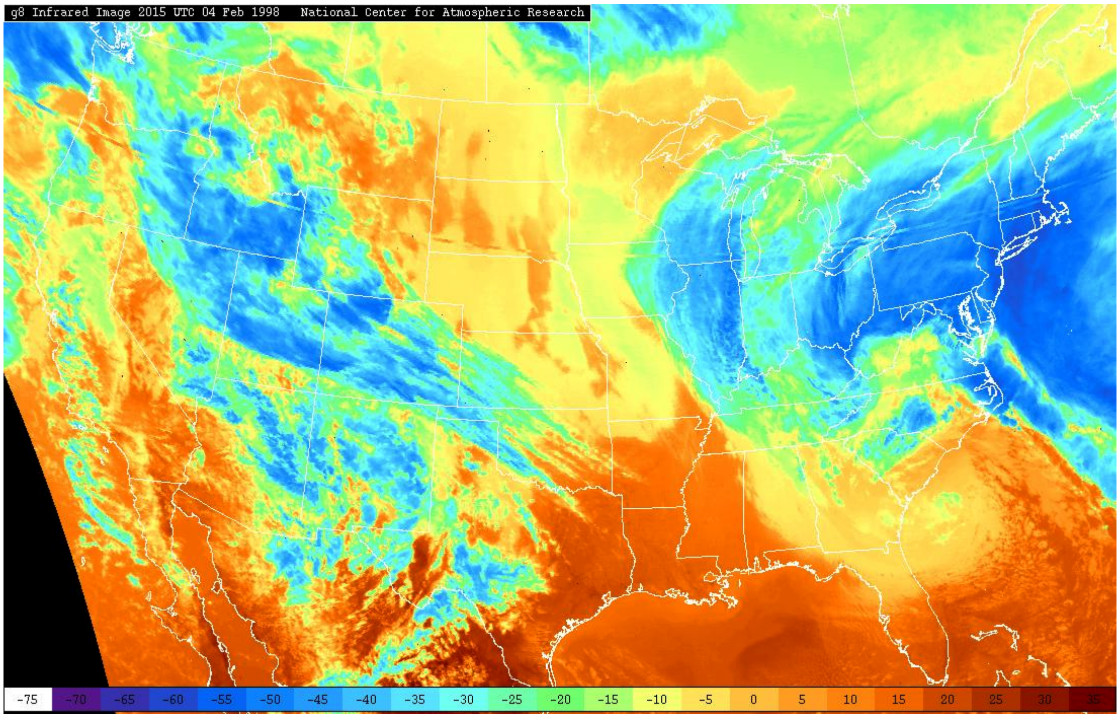


Figure 6 – GOES-8 f) infrared and g) visible satellite images for 980204, 1815 UTC.



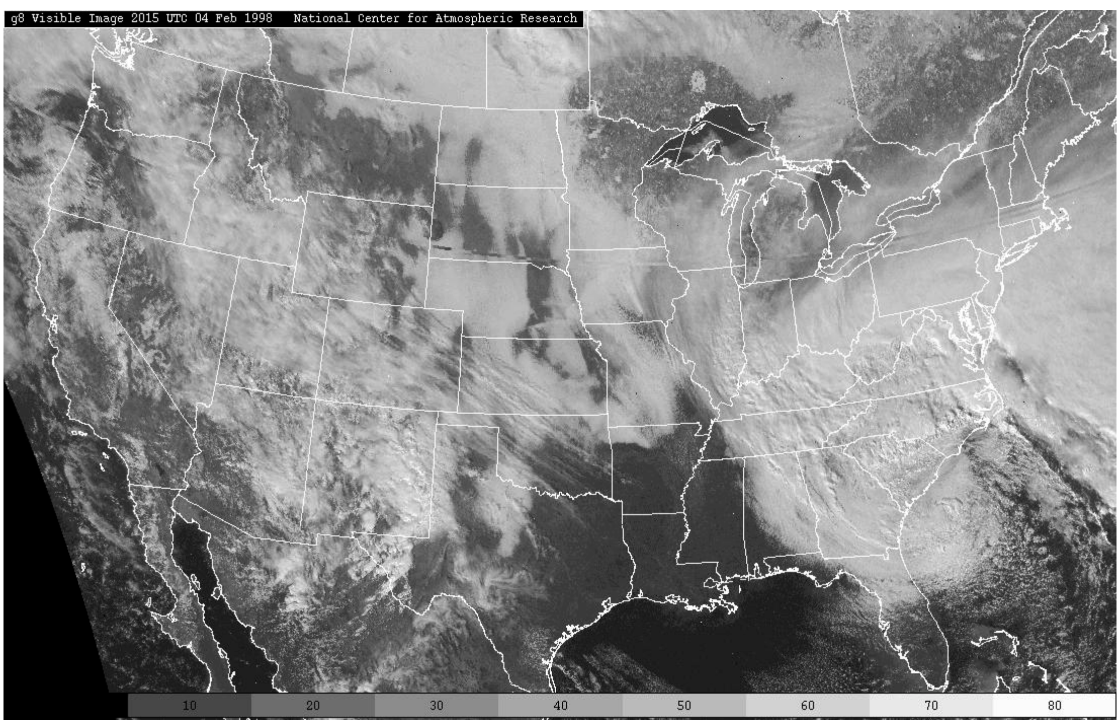
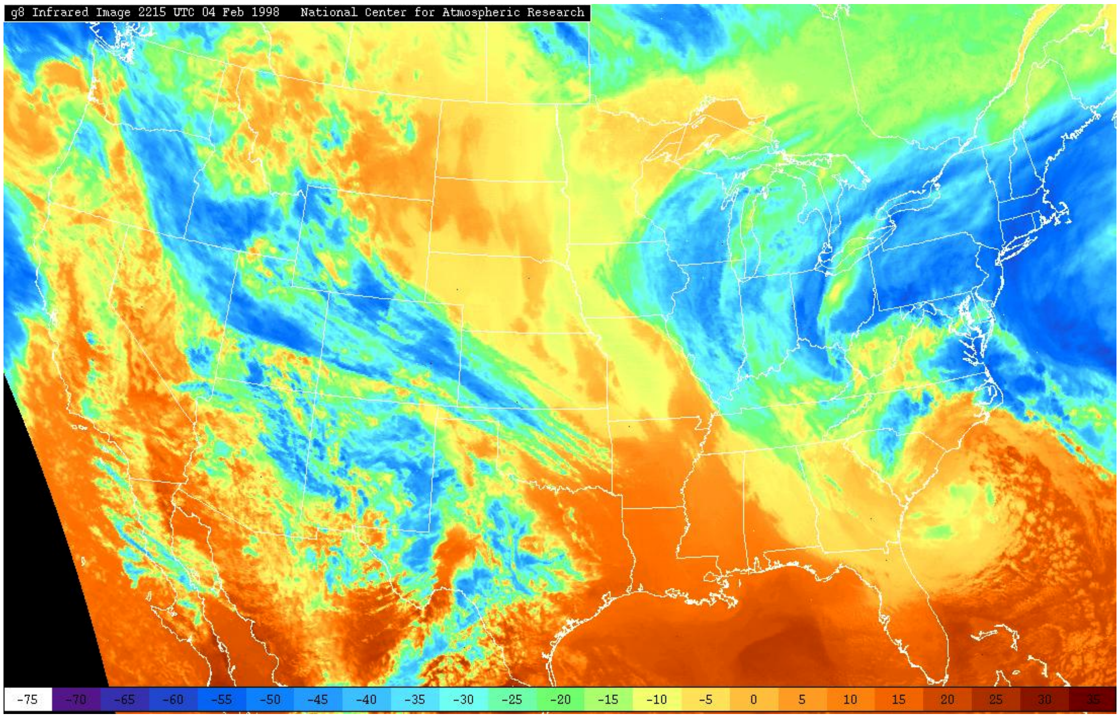


Figure 6 – GOES-8 h) infrared and i) visible satellite images for 980204, 2015 UTC.



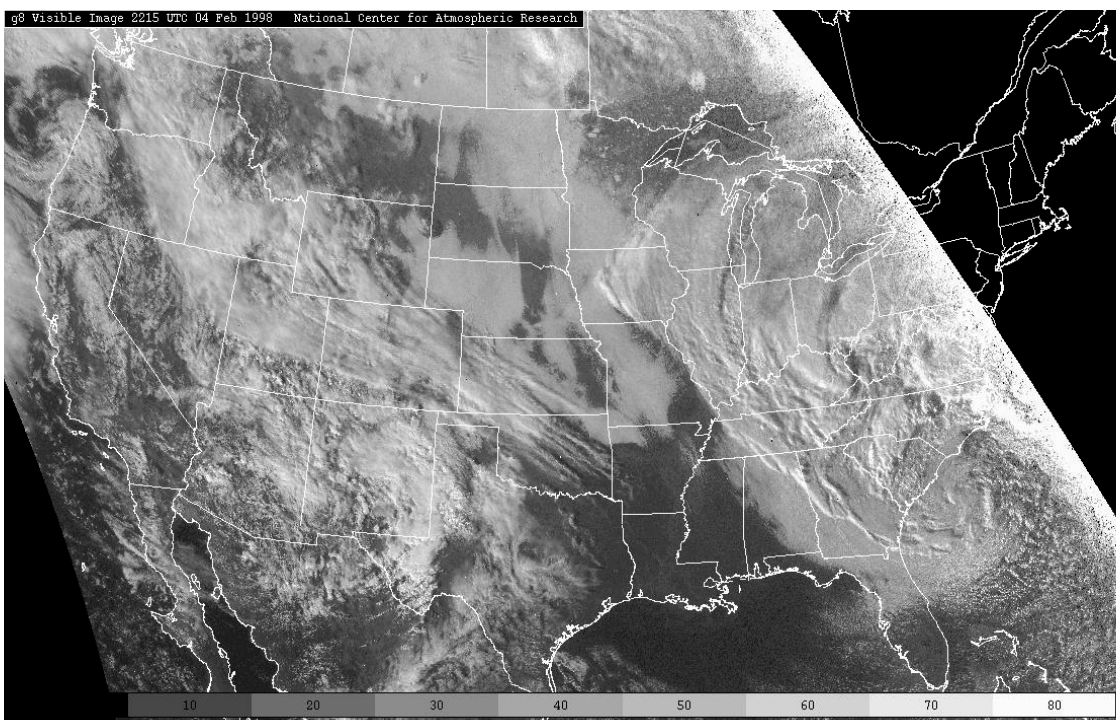
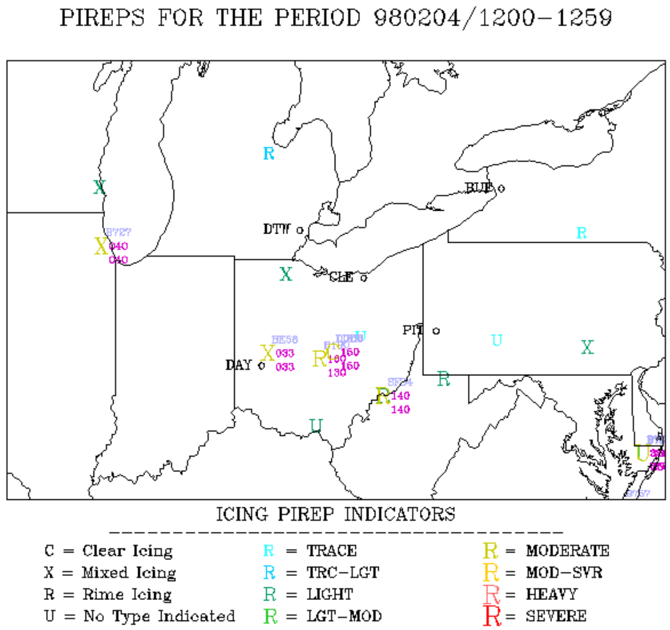


Figure 6 – GOES-8 j) infrared and k) visible satellite images for 980204, 2215 UTC.



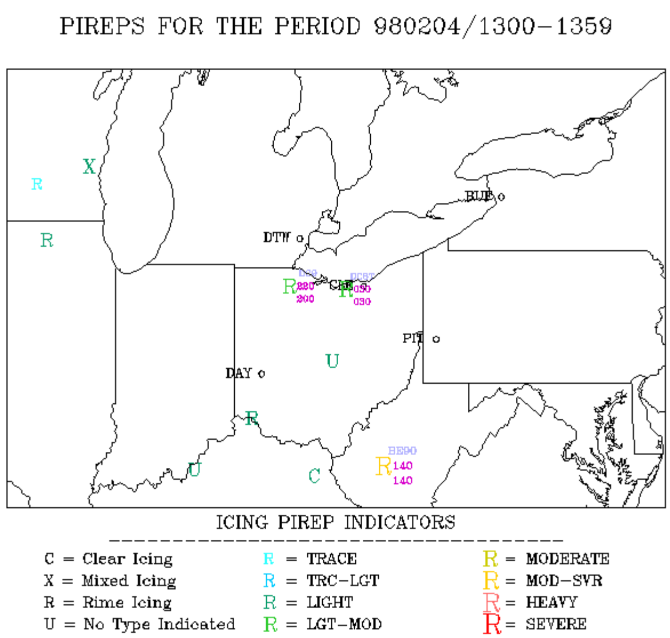
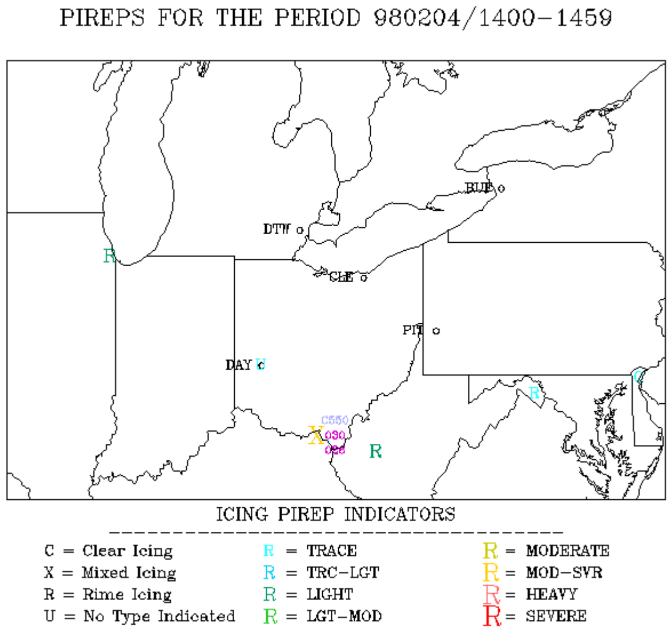


Figure 7 – Pilot reports of icing for 980204, a) 1200-1259 and b) 1300-1359 UTC.



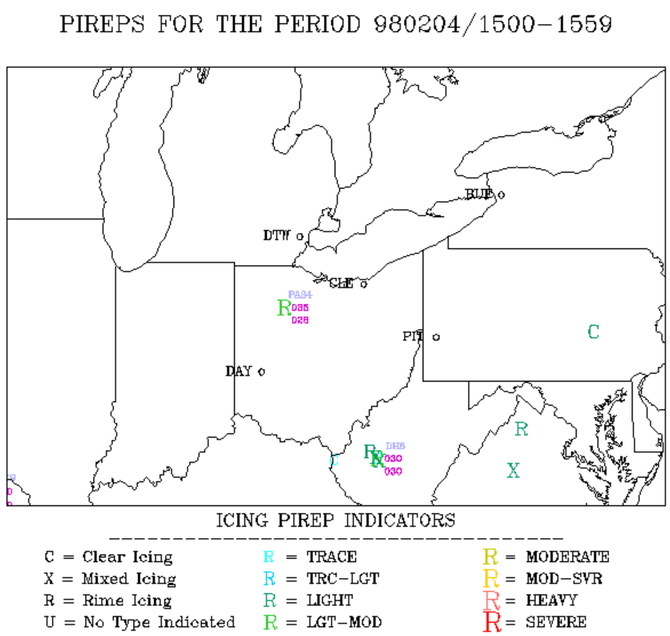
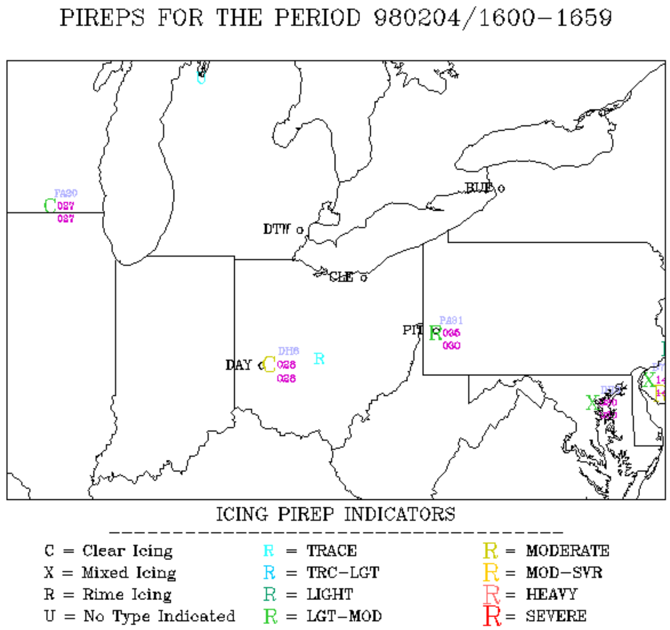


Figure 7 – Pilot reports of icing for 980204, c) 1400-1459 and d) 1500-1559 UTC.



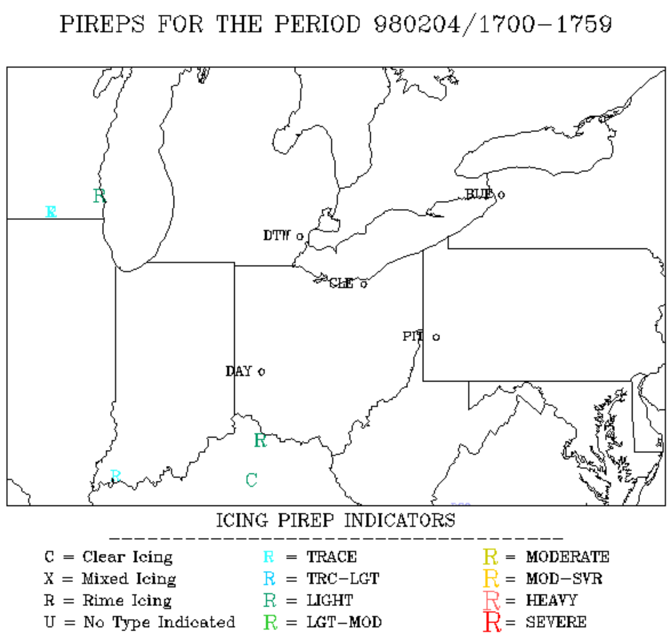
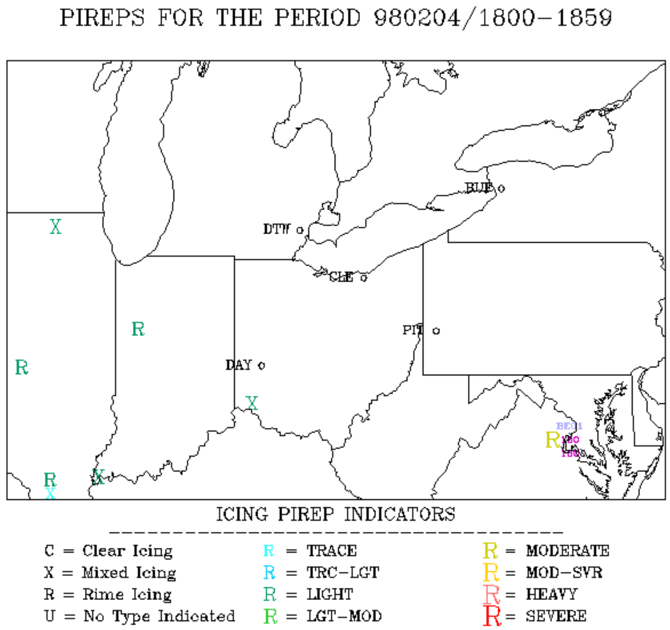


Figure 7 – Pilot reports of icing for 980204, e) 1600-1659 and f) 1700-1759 UTC.



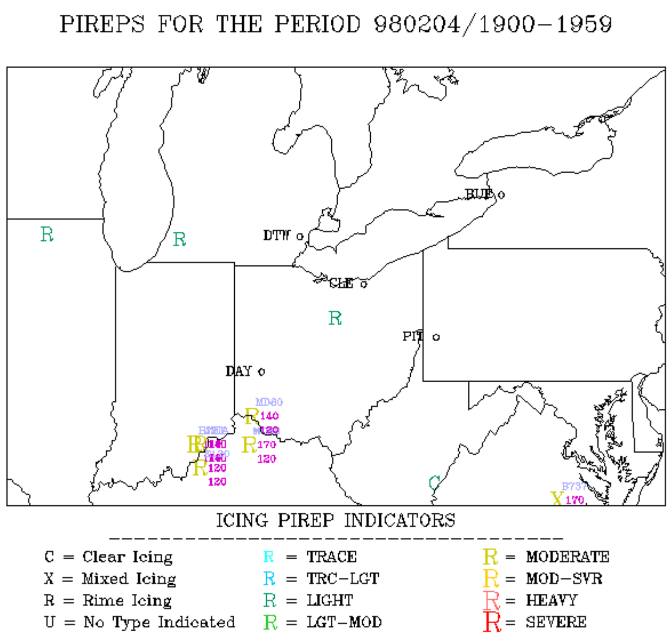
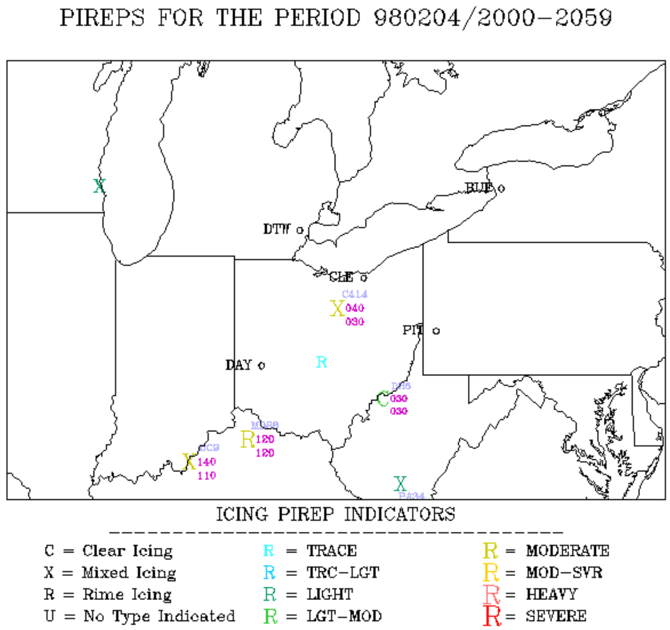


Figure 7 – Pilot reports of icing for 980204, g) 1800-1859 and h) 1900-1959 UTC.



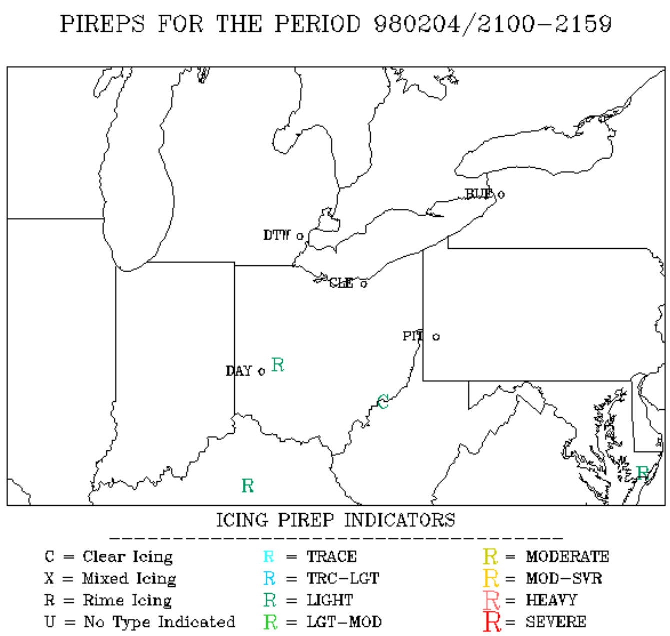


Figure 7 – Pilot reports of icing for 980204, i) 2000-2059 and j) 2100-2159 UTC.

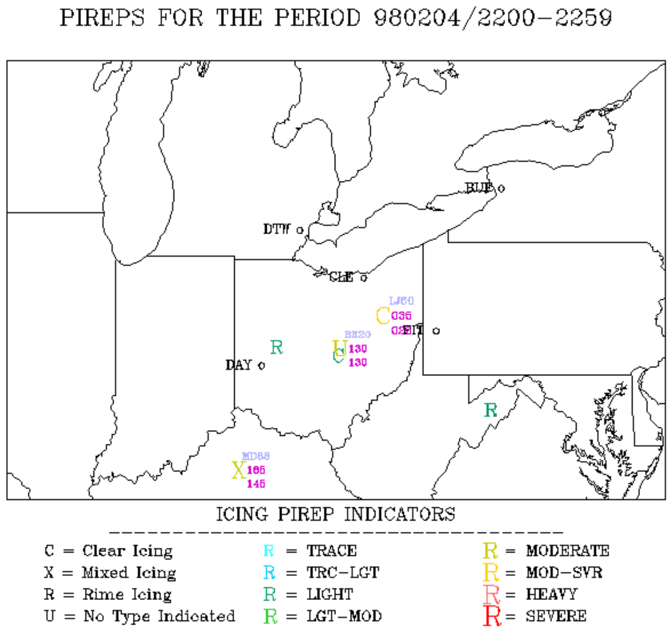


Figure 7 – Pilot reports of icing for 980204, k) 2200-2259 UTC.

February 5, 1998

Flight #1—Over Zanesville and Columbus, OH, from 1342 to 1507 UTC.

Flight #2—Over Columbus, Zanesville, and Canton-Akron, OH, from 1537 to 1740 UTC.

Brief overview

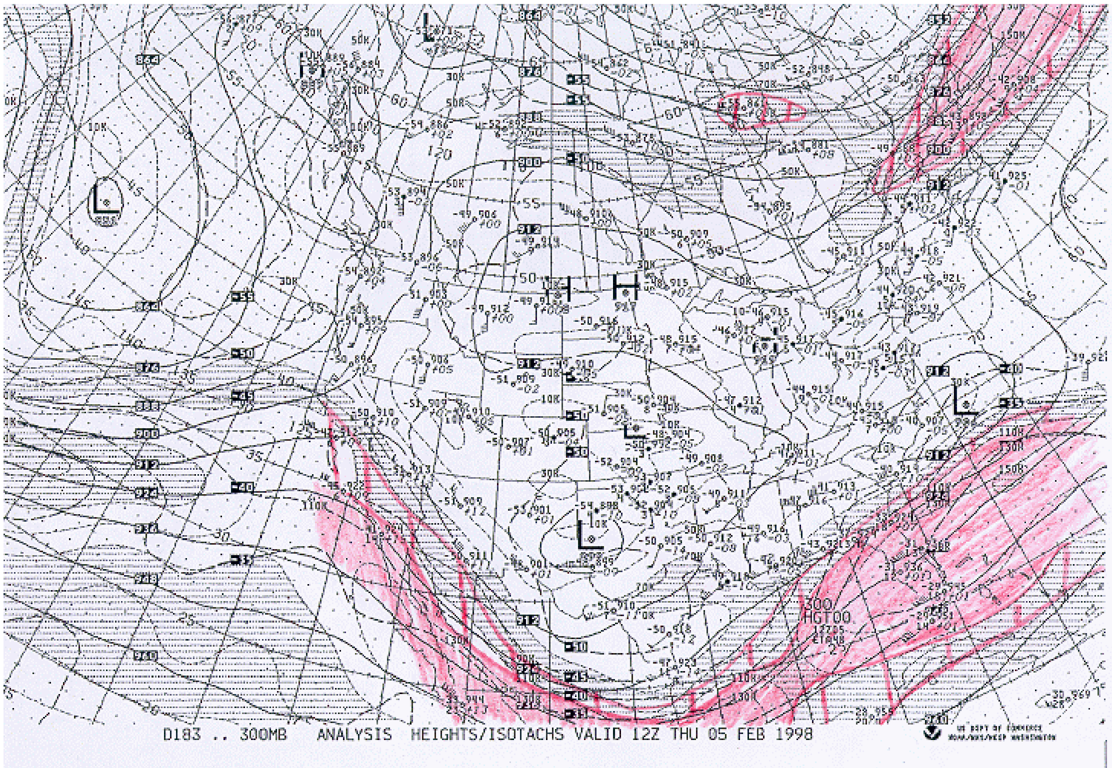
On this day, two flights were made into a deep, classical, freezing rain event over central Ohio. Initially, the first flight was made to investigate pocket of possible icing and freezing drizzle well above the upper freezing level. Mostly ice crystals and aggregates of snow were encountered upon climbout from Cleveland, but some freezing drizzle was encountered over Zanesville above 7,000 feet. The freezing drizzle was all-water at times, with LWC has high as 0.15, but was also mixed with snow at times. The Twin Otter flew into area of light snow aloft, then descended through the melting layer (4300-6200 feet) and into the subfreezing layer below to investigate freezing rain and freezing drizzle there. A strong vertical temperature gradient was encountered at the base of the melting zone, and wildly fluctuating temperatures (-3C < T < +2C) were encountered at this altitude. Some classical freezing drizzle was observed west of Zanesville, where the precipitation processes were inefficient above the melting zone. Further to the west, where the precipitation was plentiful, freezing rain was encountered near Columbus. Flights within the freezing rain (and LWC as high as 0.2) immediately below the melting zone produced little ice accumulation, seemingly because the droplets did not have adequate time to cool to the ambient temperature. On final descent into Columbus, temperatures as cold as -4C were found below cloud base at 2500 feet, but LWC values were essentially zero there. During the second flight, the Twin Otter ascended to well above the melting zone (up to 13,000 feet) in hopes of encountering further pockets of freezing drizzle aloft in small areas of lighter precipitation over Zanesville and Canton-Akron. Mostly crystals and little/no LWC were countered at all altitudes.

Relevant weather features

At 300 mb, two weak, closed lows were present over western Texas and off the North Carolina coast, with a rather strong jet to their south (Fig. 1). A ridge was in place over the forecast area, with weak southeasterly flow and moist conditions indicated there. The closed low off the North Carolina coast was somewhat stronger at 500 mb, and featured a trough which extended west from the low to Kansas. A fairly narrow swath of moisture and warm advectioin was present just to the north of this trough, from eastern Nebraska to northern Virginia, as well as across much of New England. Temperatures were between -15 and -20C over the forecast area at this level. Dry air and cold advection were present over Michigan and southeastern Ontario. At 700 mb, the closed low off the North Carolina coast was even stronger, and the trough to its west was still present. A second trough was also evident, running northeastward from the low. Saturated conditions were present across the forecast area, except for very dry air over southeastern Ontario, Michigan, and northern Indiana. Warm advection also dominated the area, despite the winds

coming from the northeast. A closed high was found over Minnesota, helping to set up the northeast winds between itself and the closed low, as well as bring in dry air from Canada. The pattern was very similar at 850 mb, and the low continued to strengthen with decreasing height. Saturated air was present to the southeast of a line from Indianapolis to Cleveland to Portland, Maine, while very dry air was present to the northwest of this line. Temperatures were ~0C and warm advection was present over the forecast area at this level. The 12 UTC Wilmington and Pittsburgh soundings (Fig. 2) show that the melting layer was present at this level, and temperatures of approximately 0C extended down to ~880 mb (~3500 feet), then cooled abruptly to -5C at 920 mb (3,000 feet). Winds also shifted abruptly from the northeast above to north northeast below this transition zone. Satellite imagery (Fig. 3) show that widespread, deep, cold (CTTs < -40C) clouds were present across the southeast portion of the forecast area during the daytime hours. In the northwest part of the forecast area (Michigan, northern Indiana), drier conditions aloft promoted breaks in the clouds.

The surface map for 12 UTC (Fig. 4) had a deep (984 mb), occluded low off the Virginia/North Carolina Coast, with an occluded front running to the northeast, and a weak trough extending to the west across North Carolina and Kentucky. Surface observations and radar data (Fig. 5) show that widespread precipitation was evident to the southeast of a line from Indianapolis to Cleveland to Albany, with a band of freezing rain evident on its northwest side, covering central Ohio, northern Pennsylvania, southeastern New York, and parts of New England. Freezing rain was also present in West Virginia, Kentucky, Virginia, and Indiana, while snow was present elsewhere to the west of the Appalachians, and rain fell within and to the east of the Appalachians. With time, the freezing rain area became smaller, and only remained over central Ohio and bits of West Virginia by 18 UTC. Most moderate or greater severity PIREPs of icing (Fig. 6) were made above 12,000 feet within or near the fringes of gaps in the radar-indicated precipitation shield, and/or within pockets of warmer CTTs. It was in these same areas that the Twin Otter found some freezing drizzle and mixed conditions aloft. PIREPs with icing of up to moderate severity were also given below 4000 feet in the freezing rain and freezing drizzle layer below the melting zone.



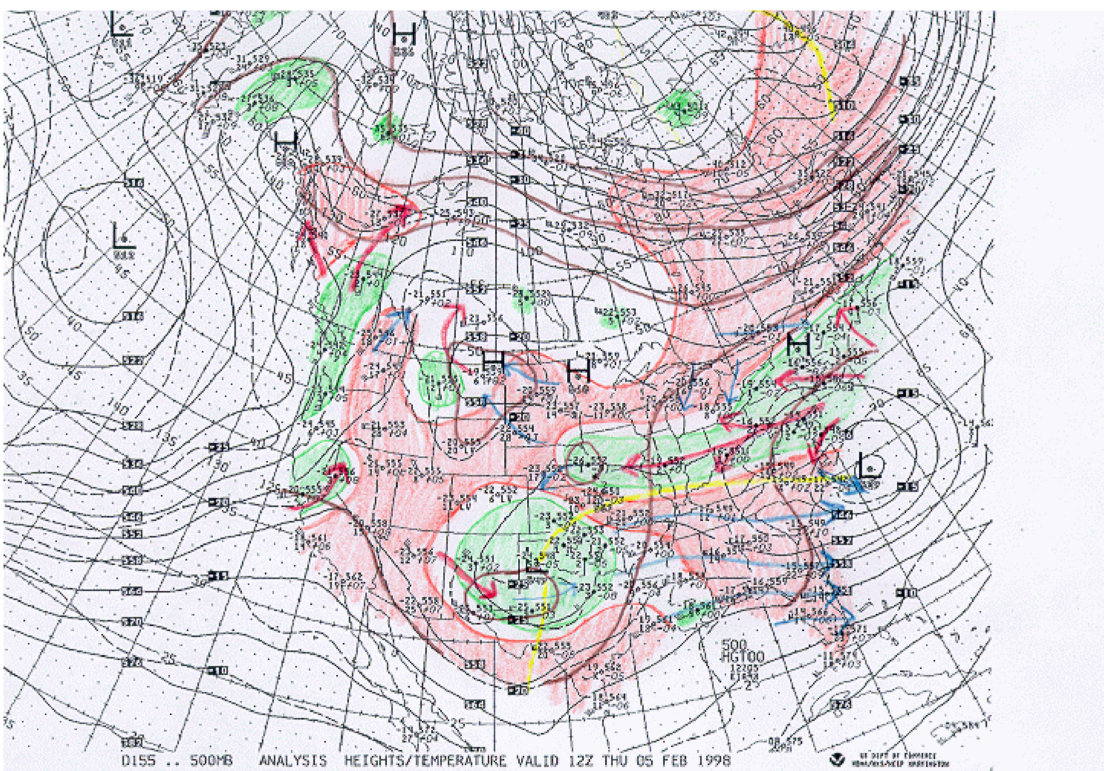
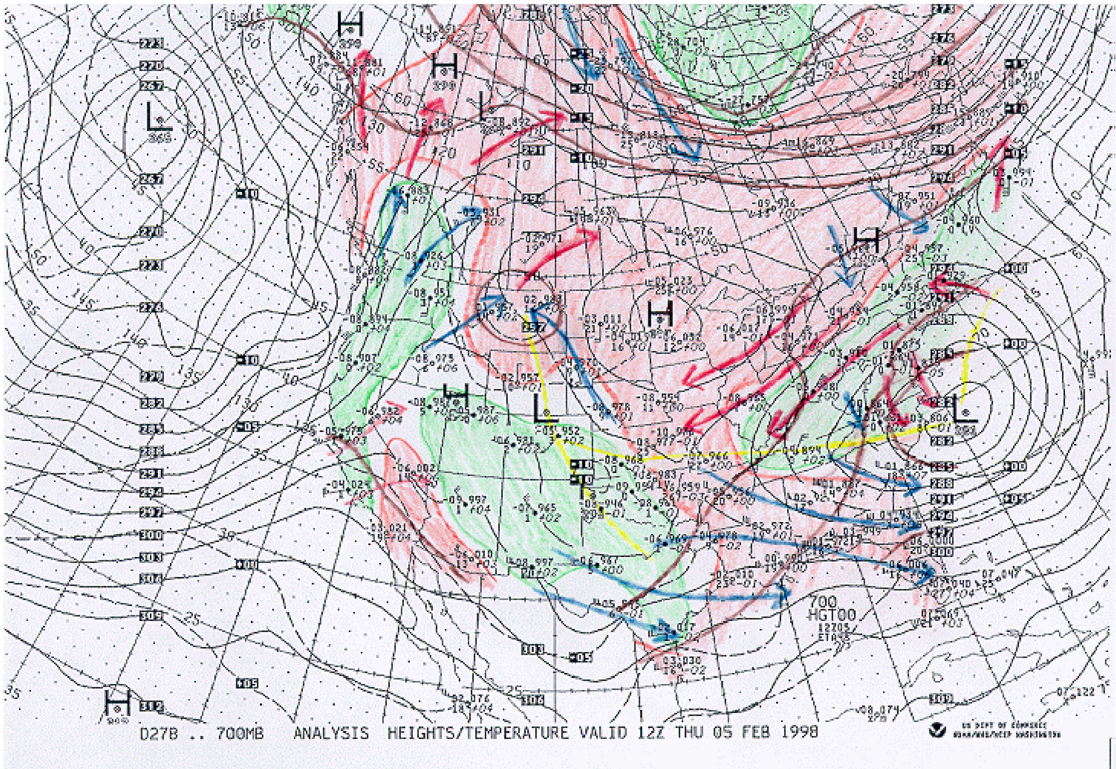


Figure 1 – Upper-air charts for 980205, 1200 UTC at a) 300 and b) 500 mb.



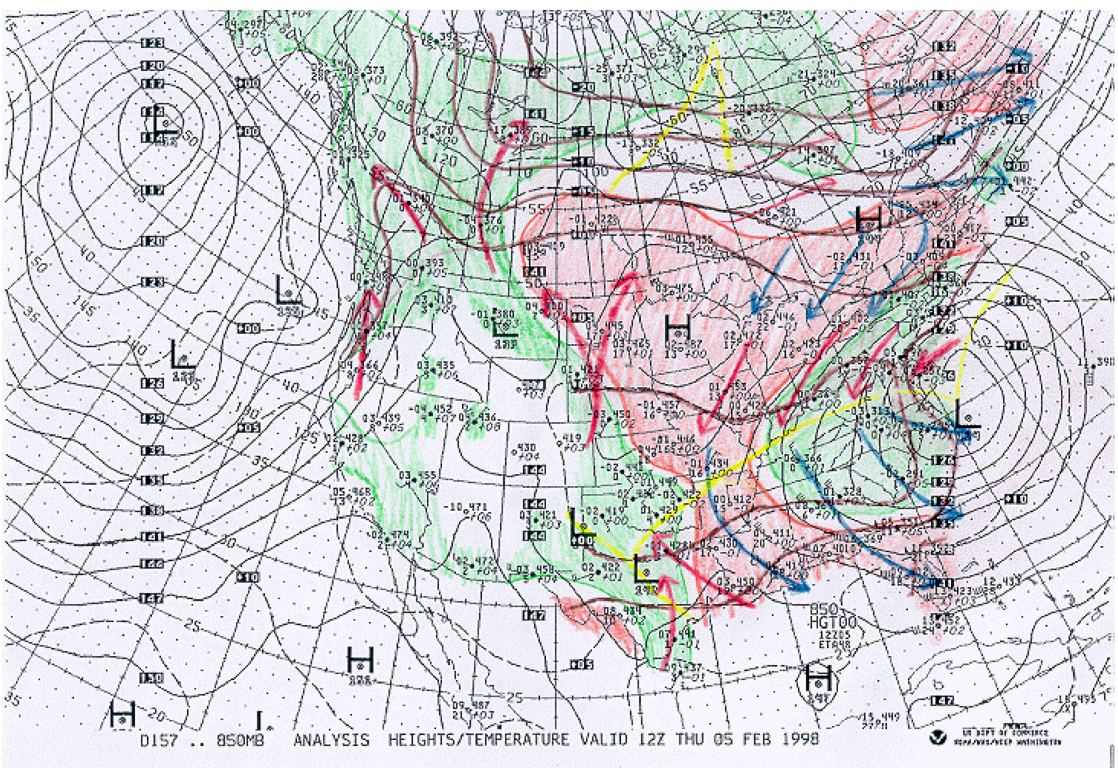
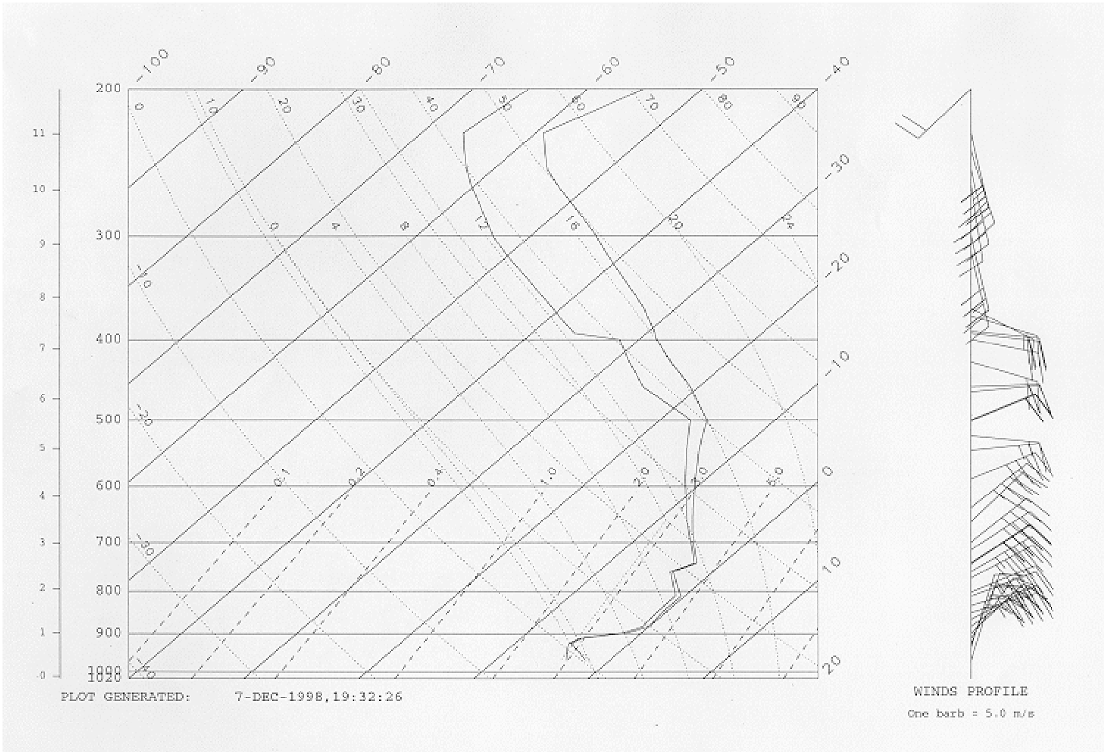


Figure 1 – Upper-air charts for 980205, 1200 UTC at c) 700 and d) 850 mb.



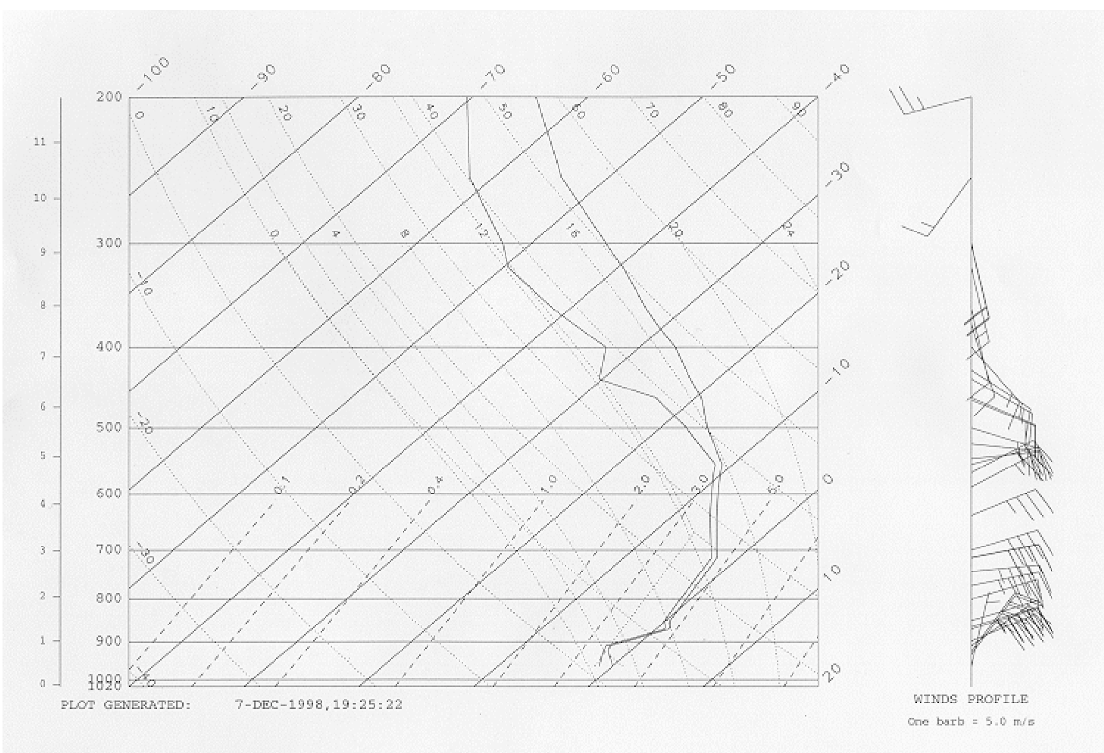


Figure 2 – Balloon-borne soundings from a) Wilmington and b) Pittsburgh at 980205, 1200 UTC.

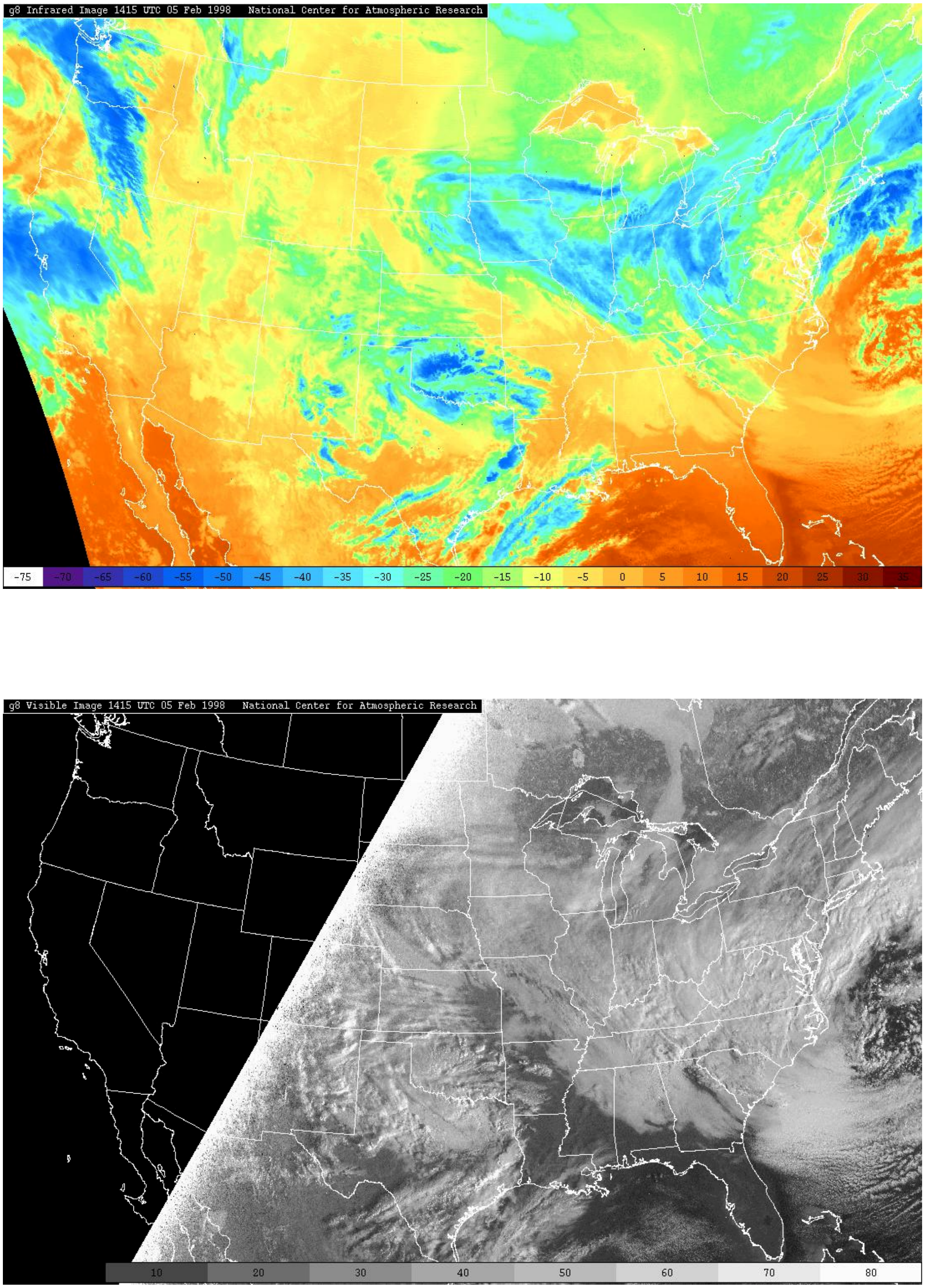
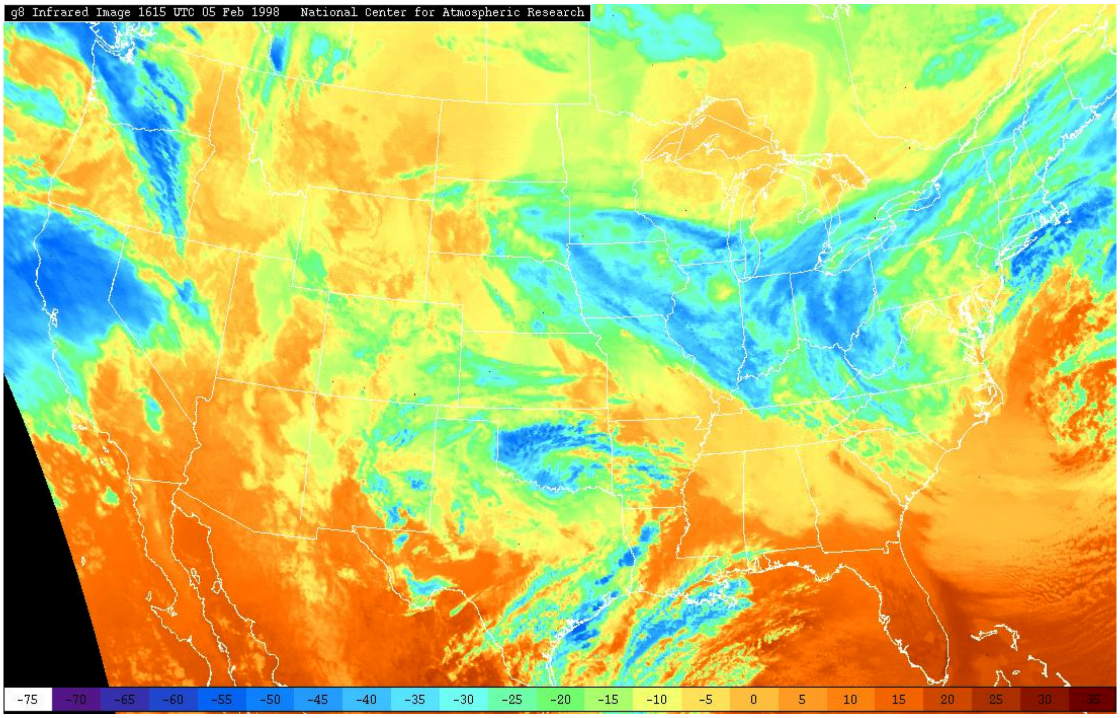


Figure 3 – GOES-8 a) infrared and b) visible satellite images for 980205, 1415 UTC.



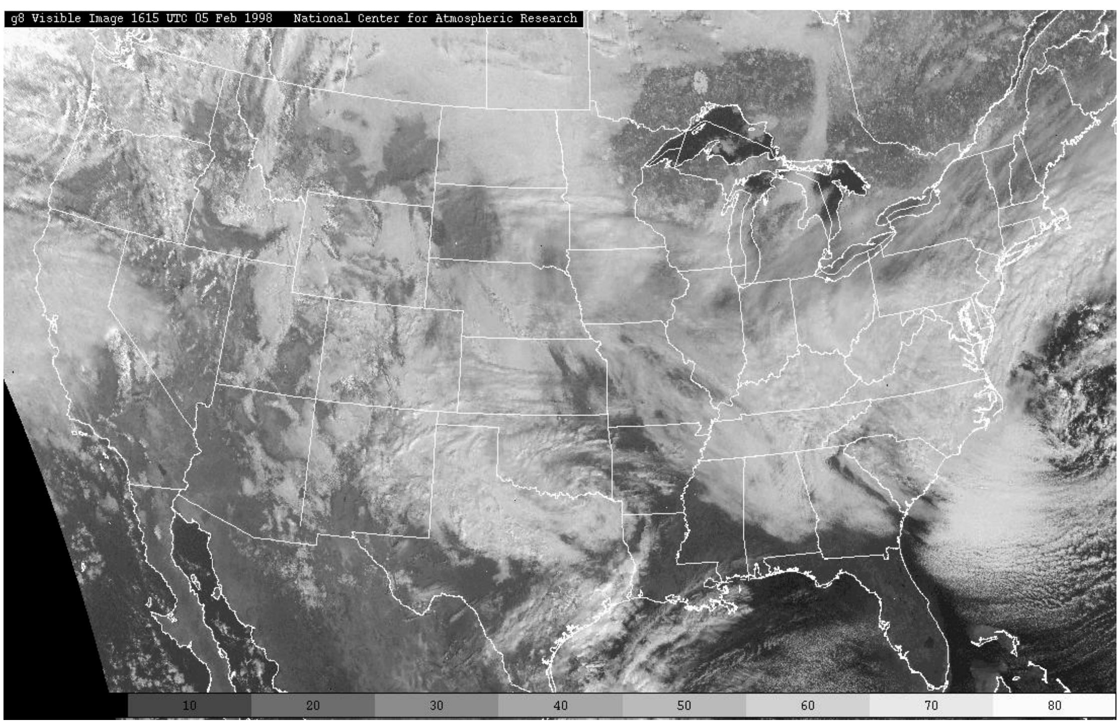
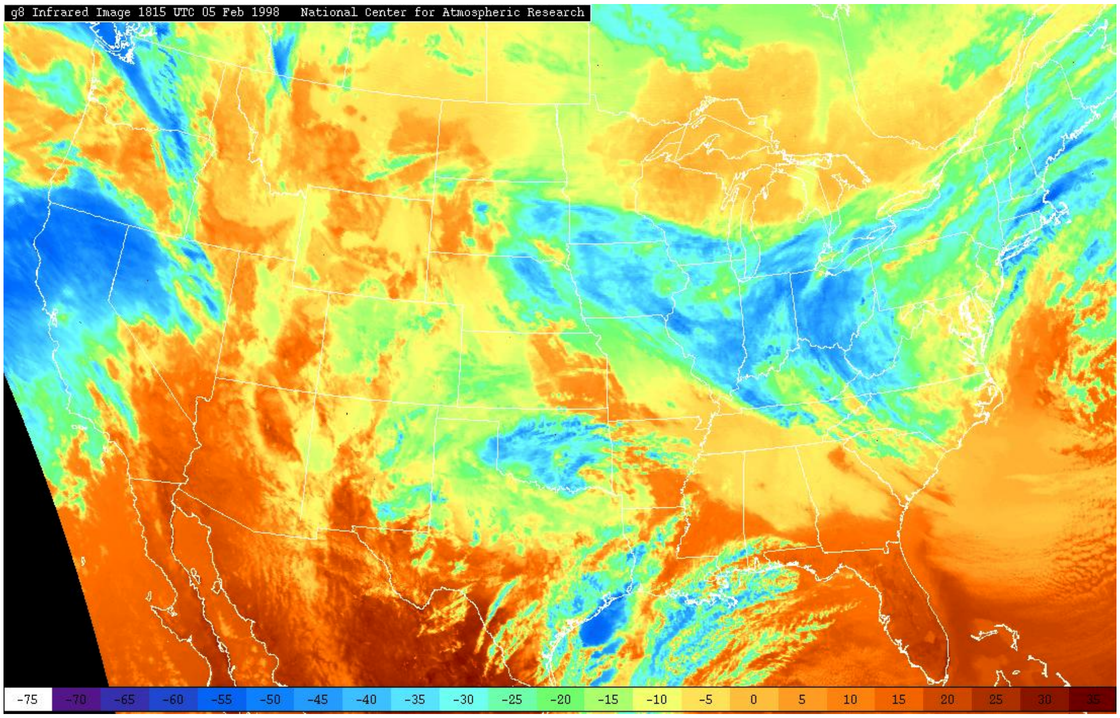


Figure 3 – GOES-8 c) infrared and d) visible satellite images for 980205, 1615 UTC.



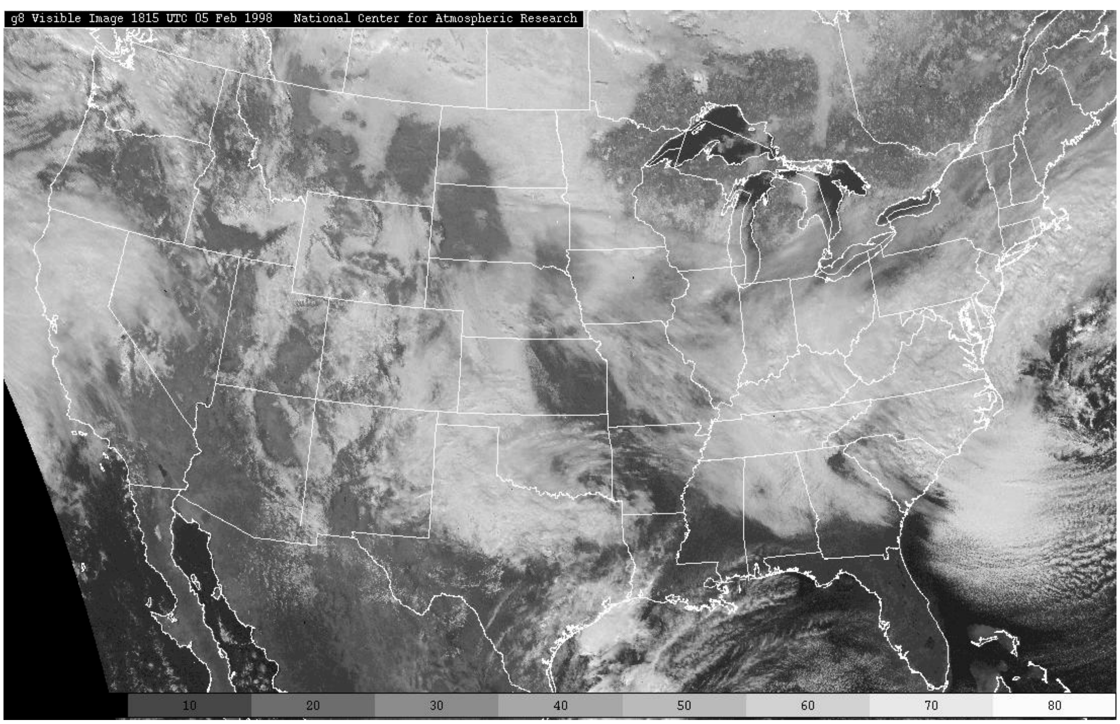
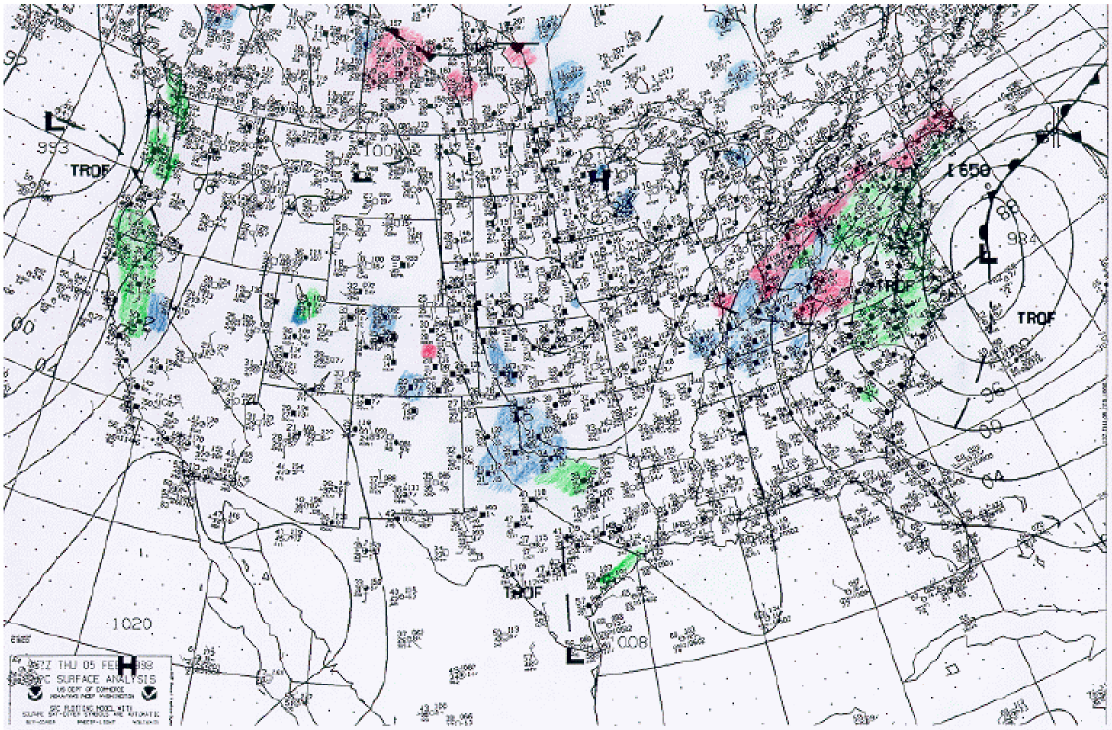


Figure 3 – GOES-8 e) infrared and f) visible satellite images for 980205, 1815 UTC.



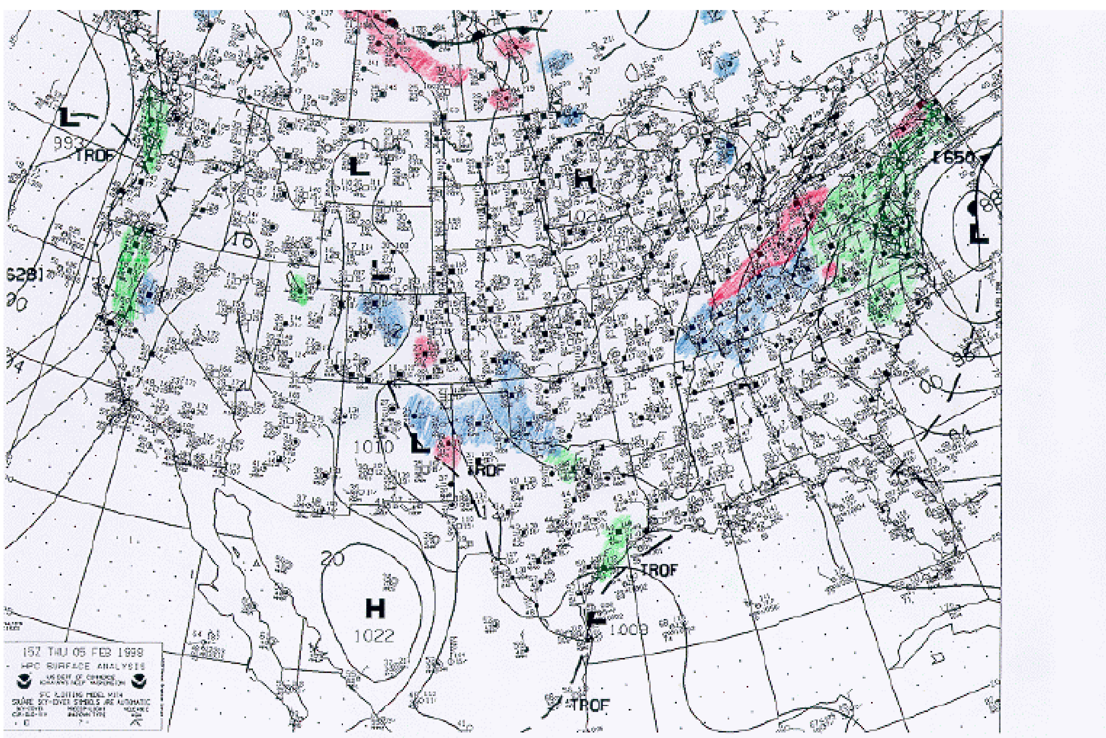
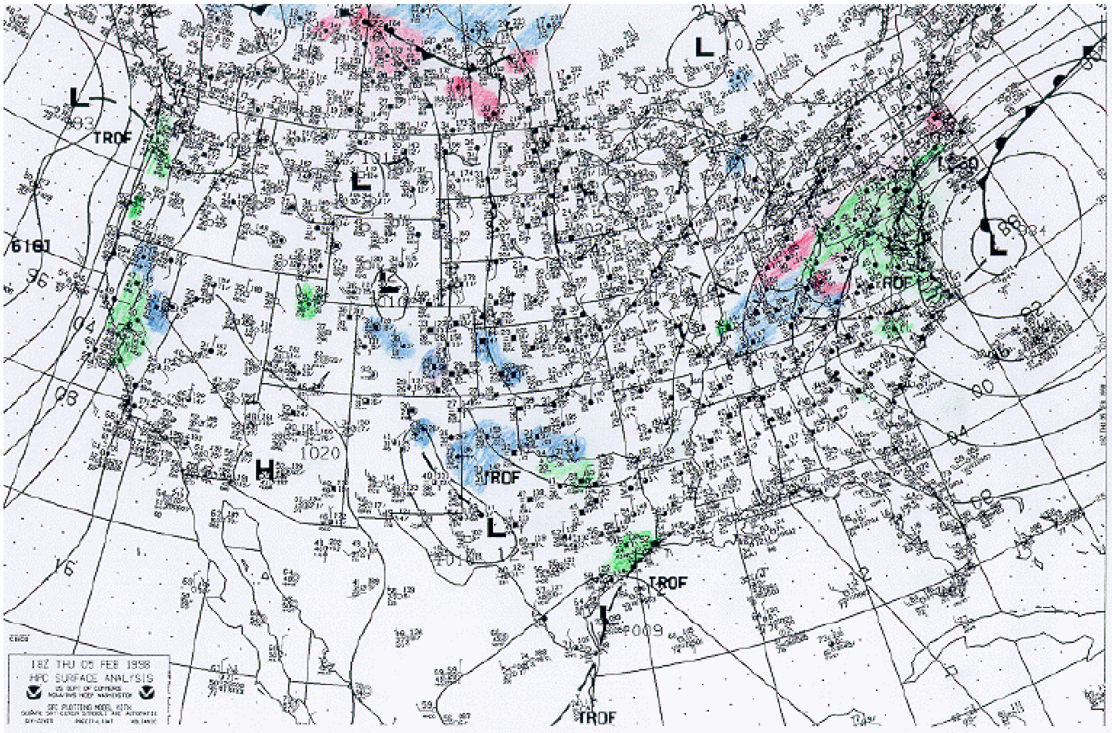


Figure 4 – Surface charts for 980205, a) 1200 and b) 1500 UTC.



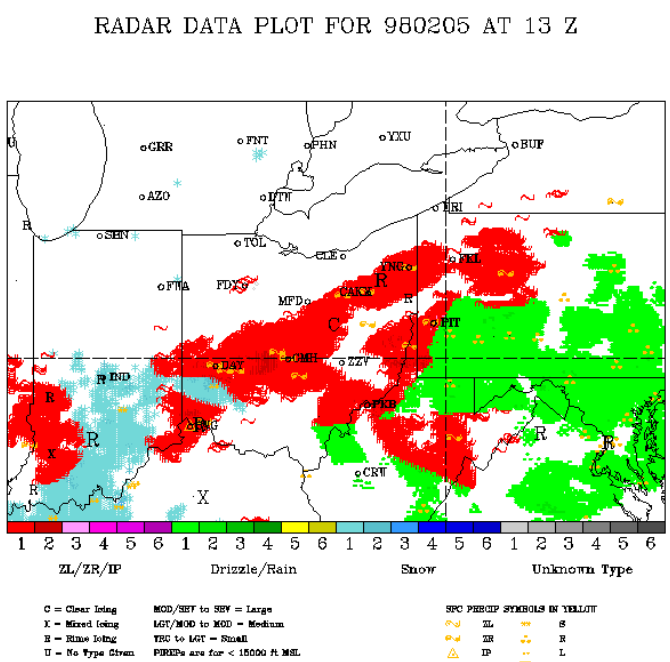
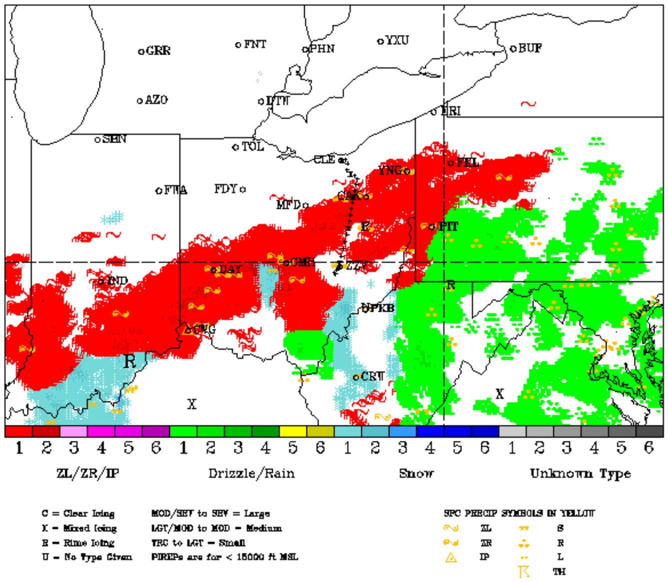


Figure 4 – Surface charts for 980205, c) 1800 UTC.
Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980205, a) 1300 UTC.

RADAR DATA PLOT FOR 980205 AT 14 Z



RADAR DATA PLOT FOR 980205 AT 15 Z

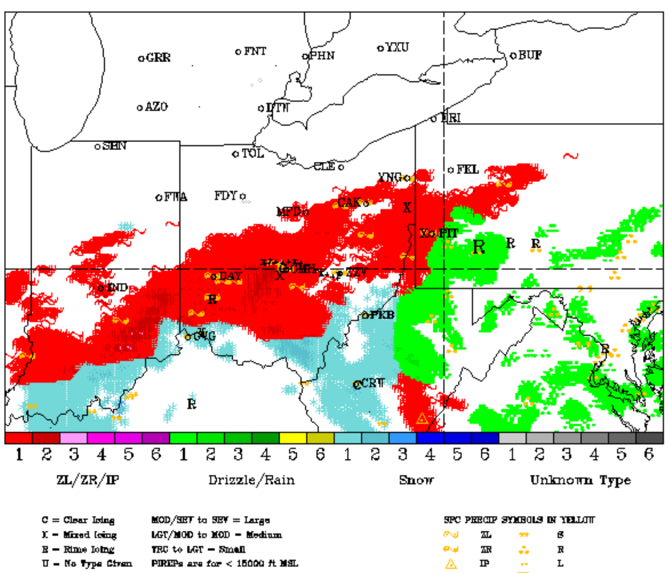
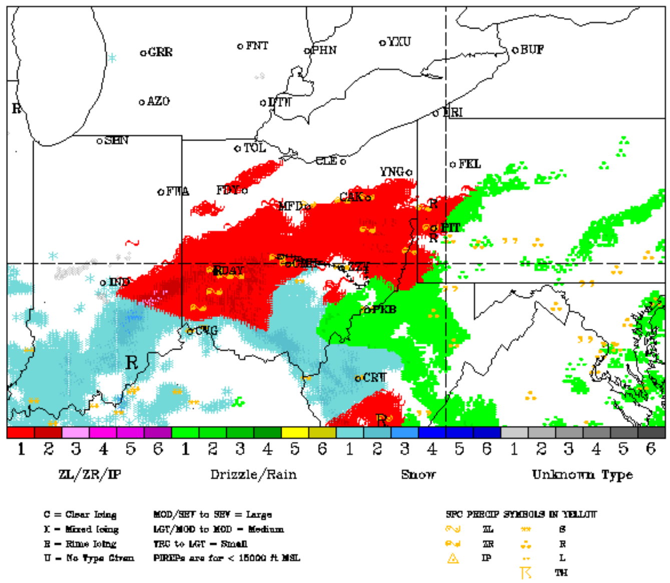


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980205, b) 1400 and c) 1500 UTC.

RADAR DATA PLOT FOR 980205 AT 16 Z



RADAR DATA PLOT FOR 980205 AT 17 Z

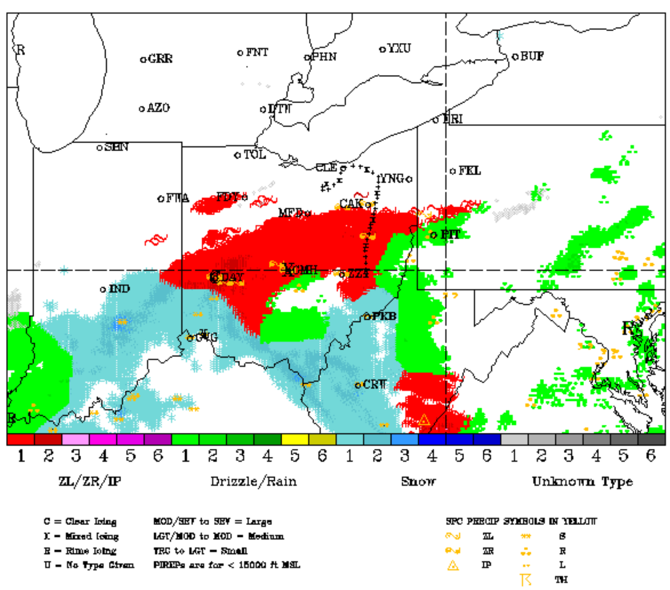
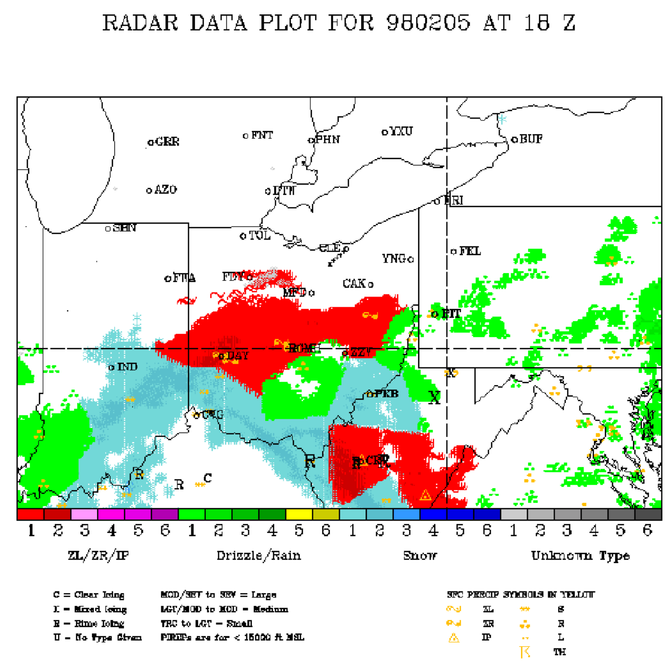


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980205, d) 1600 and e) 1700 UTC.



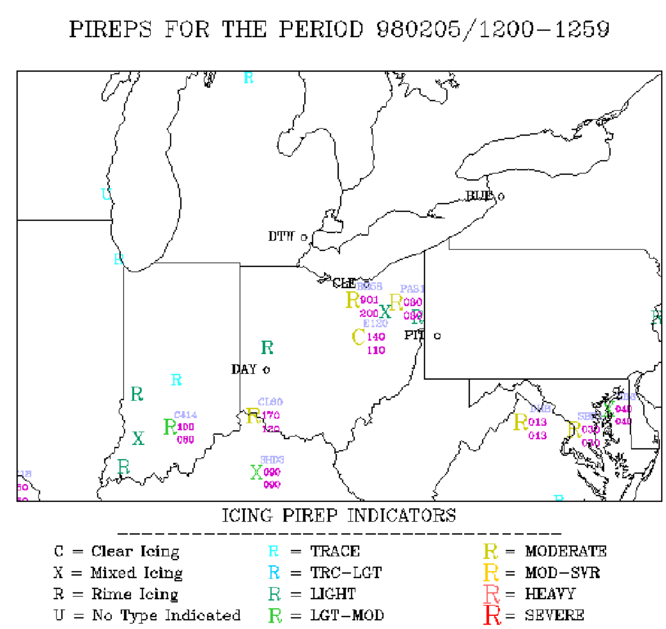
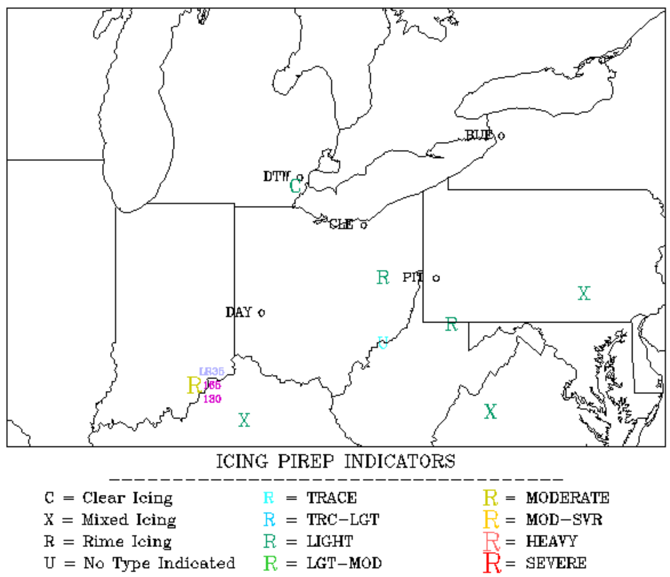


Figure 5 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980205, f) 1800 UTC.

Figure 6 – Pilot reports of icing for 980205, a) 1200-1259 UTC.

PIREPS FOR THE PERIOD 980205/1300-1359



PIREPS FOR THE PERIOD 980205/1400-1459

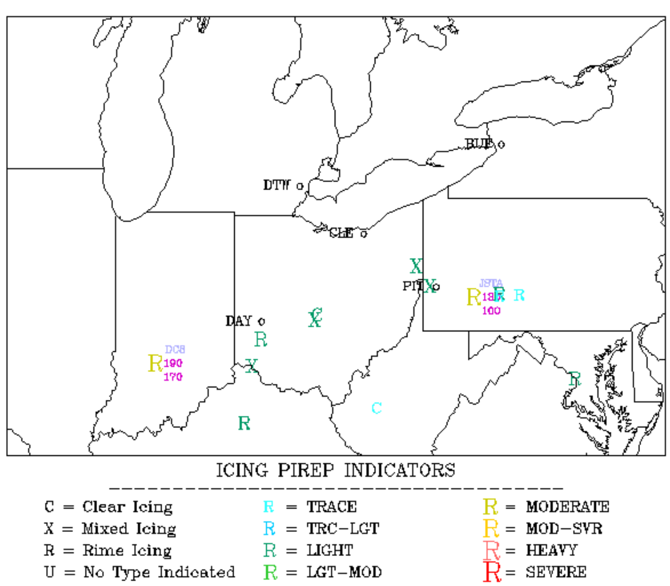
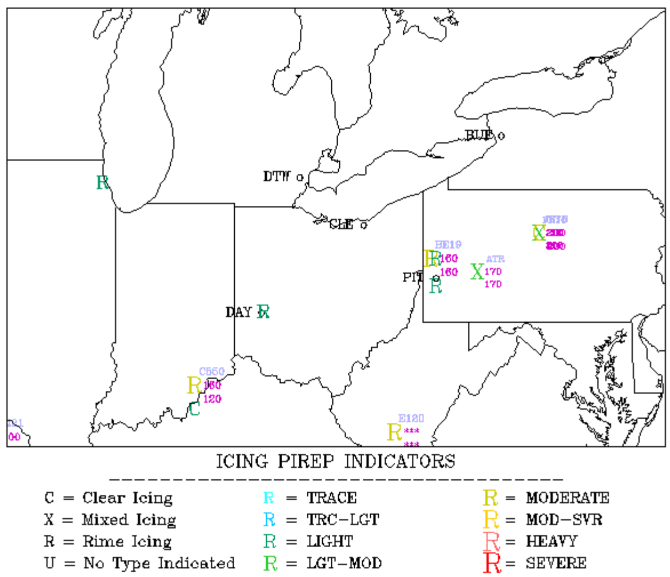


Figure 6 – Pilot reports of icing for 980205, b) 1300-1359 and c) 1400-1459 UTC.

PIREPS FOR THE PERIOD 980205/1500-1559



PIREPS FOR THE PERIOD 980205/1600-1659

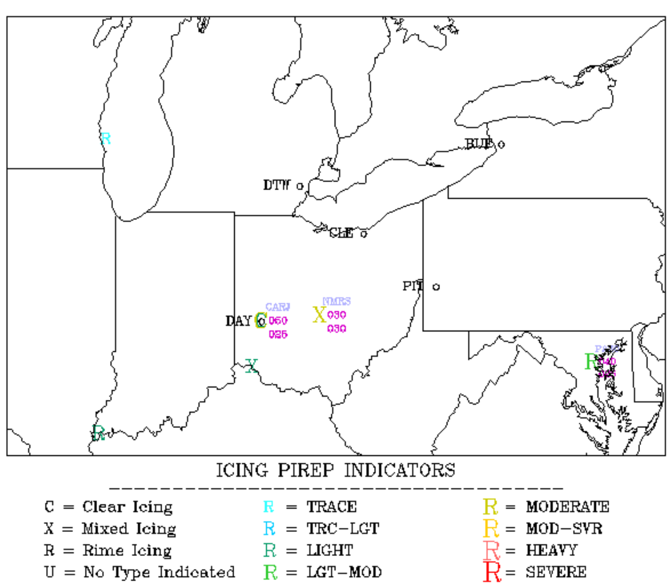


Figure 6 – Pilot reports of icing for 980205, d) 1500-1559 and e) 1600-1659 UTC.

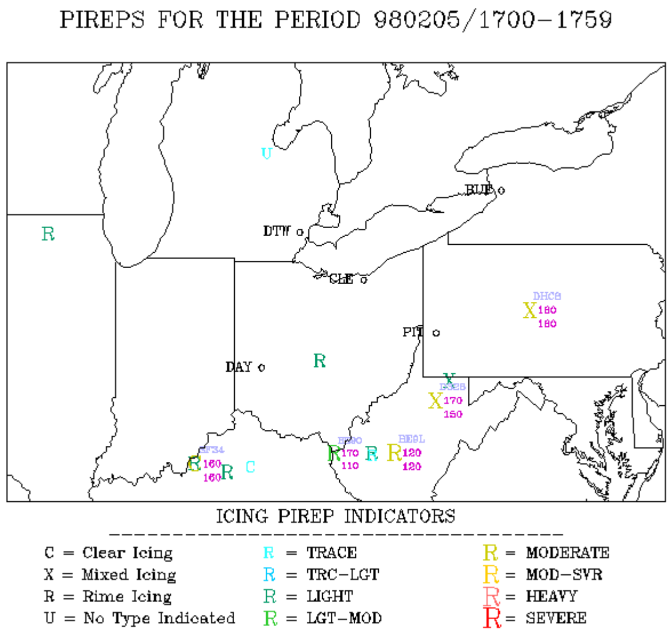


Figure 6 – Pilot reports of icing for 980205, f) 1700-1759 UTC.

February 12, 1998

Flight #1—Over Lake Erie and near Selfridge AFB from 1559 to 1741 UTC.

Flight #2—Over Selfridge AFB and Toledo, OH, from 1905 to 2022 UTC.

Brief overview

Two flights were made on this day into fairly shallow clouds comprised of mostly small droplets. During the first flight, small-drop clouds with LWC up to 0.45 were sampled during ascent from Cleveland. The cloud bases and tops were near 2400’ and 4000’, respectively, and CTT was –6C. Broken clouds with variable tops and depths were present over and to the north of Lake Erie. More solid, but still shallow, clouds were sampled along the southern shore of Lake Huron. The cloud bases and tops were slightly higher (4000’ and 4900’, respectively), cloud tops were slightly colder (CTT = -7C), and fairly steady, lower values of LWC were present (0.1-0.3). A few ice crystals were observed to the north of Lake Erie.

During the second flight, similar conditions were observed near Toledo. The primary differences were that the clouds were slightly deeper, they had slightly colder cloud tops (CTT = -8C), and higher LWCs (up to 0.5) along the southern shore of Lake Erie. A few ice crystals and possibly a few freezing drizzle drops were found along the northwestern shore of the lake, to the north of Toledo.

Relevant weather features

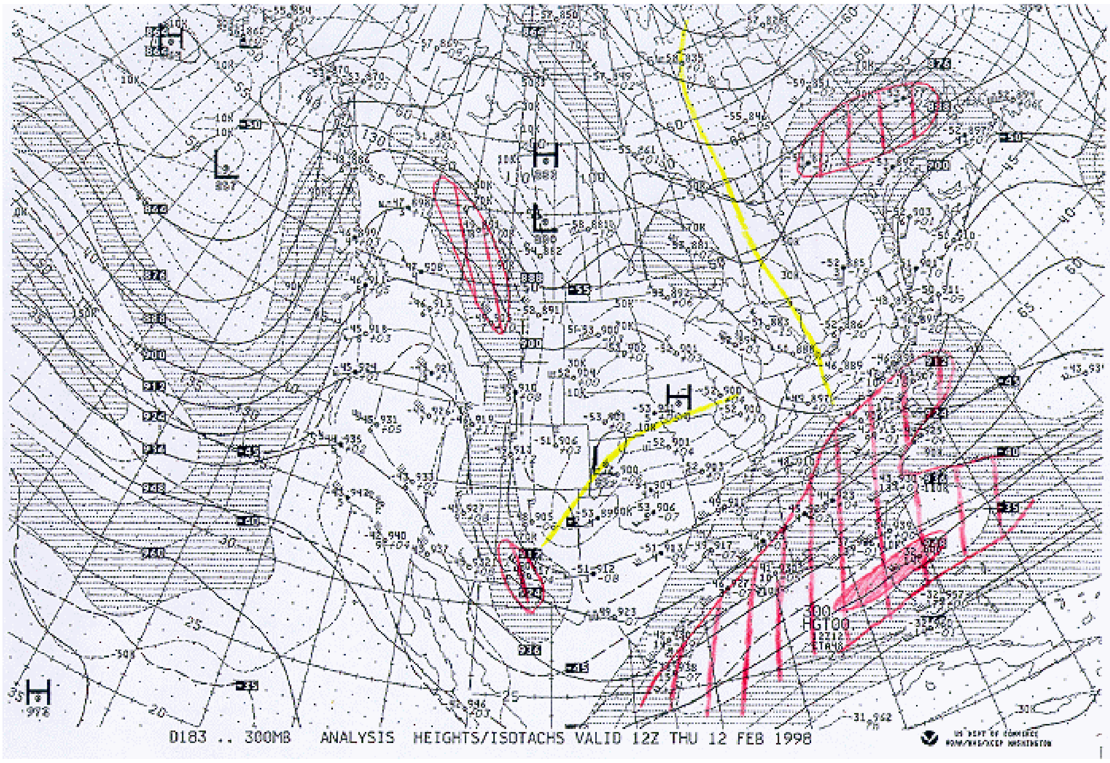
At 1200 UTC, a roughly north-south oriented trough ran through eastern Ohio at 300 mb (Fig. 1).

The trough was also present at 500 mb, but was over the Ohio-Pennsylvania border. Saturated air was present across Pennsylvania, eastern Ohio, southeastern Michigan, and across Ontario to western New York state. Dry air covered the surrounding area. Moist air covered most of the forecast area at 700 mb, with the exceptions of western Michigan and northwestern Indiana. A weak low was centered to the northeast of Lake Huron, and the main trough featured a secondary split that ran from Cleveland to southern Illinois. Cold advection dominated the region, except for a small pocket of warm advection ahead of the secondary trough, over northern Ohio. At 850 mb, the secondary trough became dominant. Strong cold advection trailed it, while a pocket of warm advection covered the southeastern half of Ohio, as well as southward into Tennessee. This was caused by westerly flow between a thermal ridge over western Ohio and Kentucky and thermal trough over the Pennsylvania-Ohio border and West Virginia. Cold advection was present on the east side of the thermal trough. Saturated air covered the entire forecast area at 850 mb.

The 1200 UTC surface chart (Fig. 2) showed the trough across Ohio, extending from a 995 mb low centered over Lake Ontario. Northwesterly and westerly winds prevailed behind and ahead of the trough, respectively. Rain fell across Ohio, much of West Virginia, and to the northeast. Snow fell along the northwestern edge of the precipitation. Radar data for 1300 UTC (Fig. 3) show that although the rain was widespread, nearly all of the significant rain was limited to the areas to the northeast of Columbus. By

1800 UTC, most of the precipitation moved out of the state, while the aircraft investigated the non-precipitating clouds around Lake Erie and the southern end of Lake Huron. Satellite data (Fig. 4) show that these clouds were fairly warm (CTTs near -10C), and had some breaks over Lake Erie and eastern Michigan. Soundings taken at Alpena MI were fairly representative of the clouds behind the surface trough, with deep northwesterly winds, unstable lapse rates, CTTs near –10C, and a strong cap (Fig. 5). These clouds thinned out a bit by 0000 UTC. The 1200 UTC Detroit sounding ascended through the snow on the back edge of the precipitation shield. Conditions dried out almost entirely at Detroit by 0000 UTC. The Wilmington soundings showed similar drying, but deeper, more stable, warm cloud was present there at 1200 UTC.

Moderate severity rime and mixed PIREPs were common across the region during the day (Fig. 6). Early on, the PIREPs were made at altitudes of 10,000’ to 14,000’ over Ohio, while lower altitude (4000’-6000’) icing was indicated over Michigan and Indiana. As the deeper clouds and precipitation moved off to the east, the Ohio PIREPs reflected shallower nature of the clouds, with all reports made at altitudes of 5,000 feet or less.



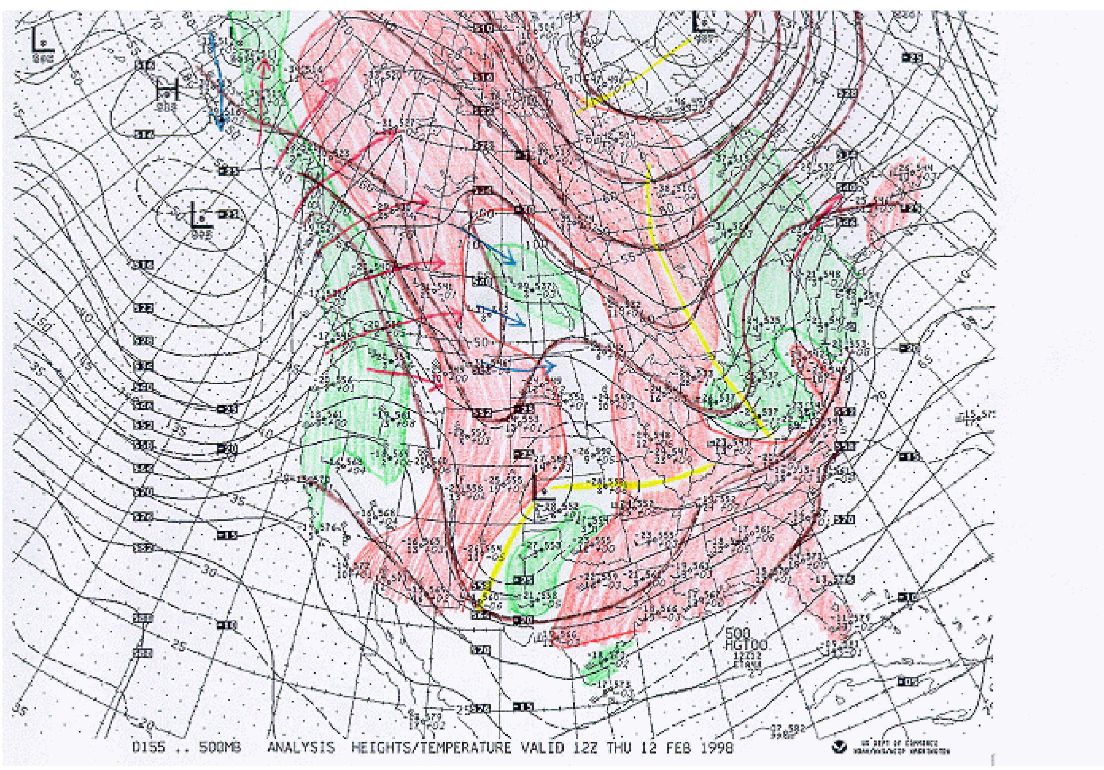
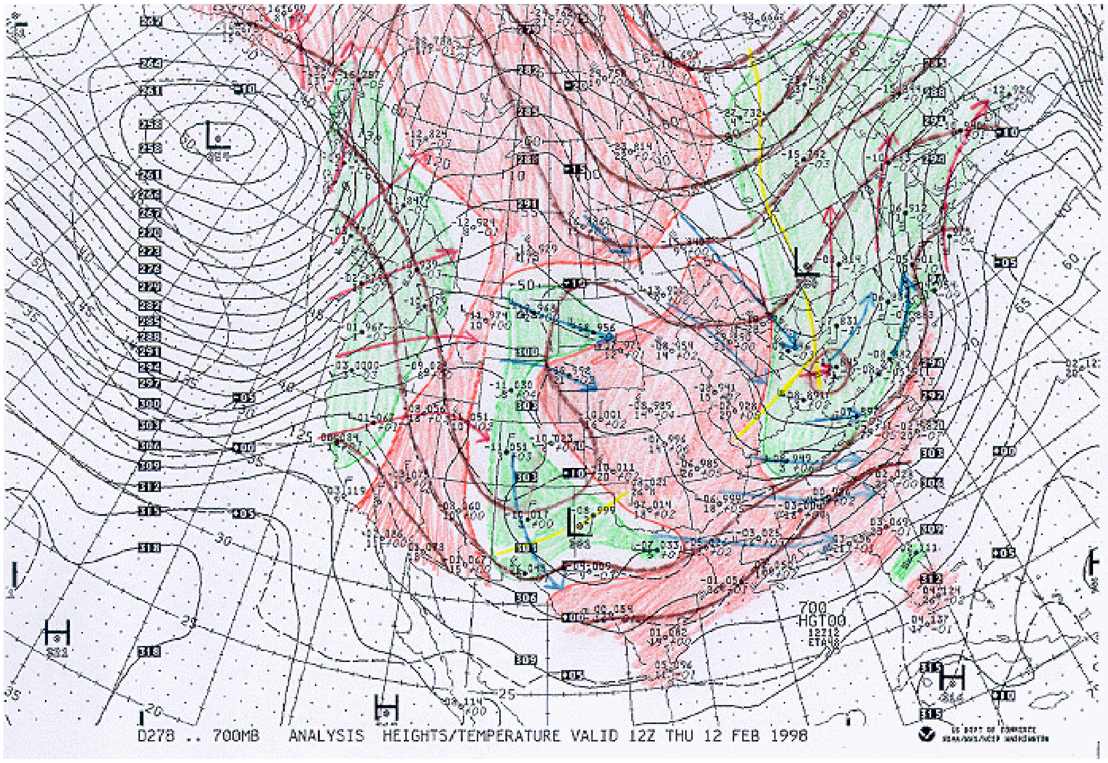


Figure 1 – Upper-air charts for 980212, 1200 UTC at a) 300 and b) 500 mb.



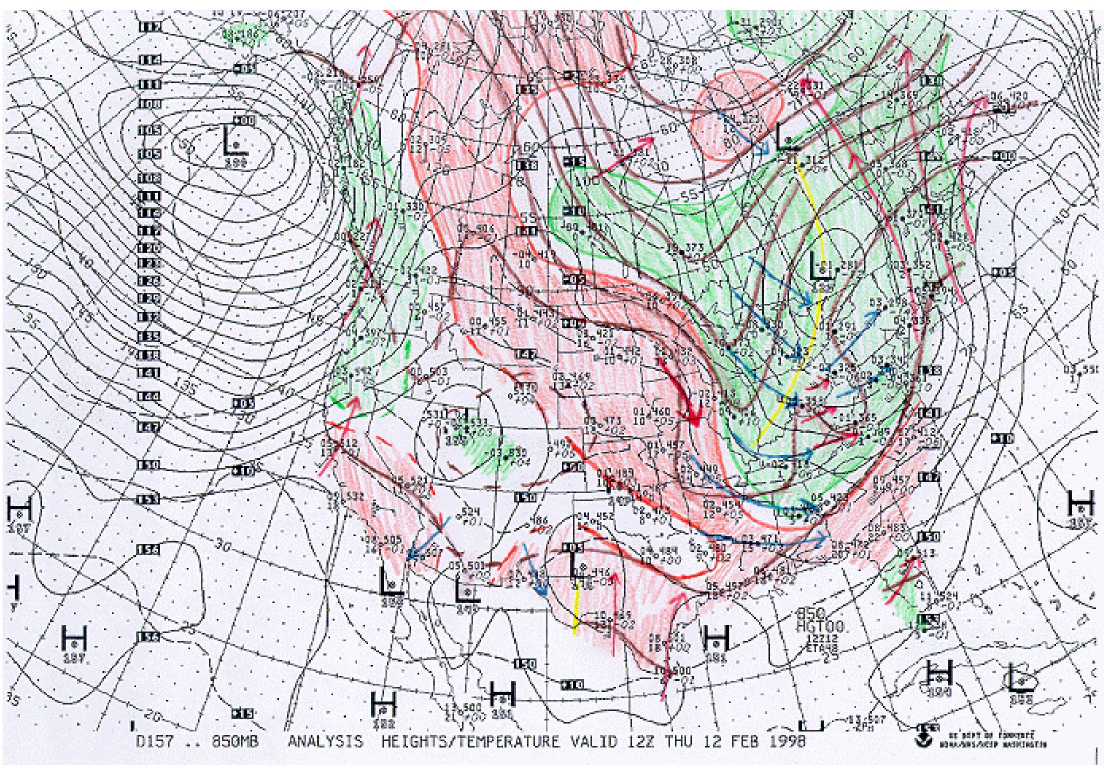


Figure 1 – Upper-air charts for 980212, 1200 UTC at c) 700 and d) 850 mb.

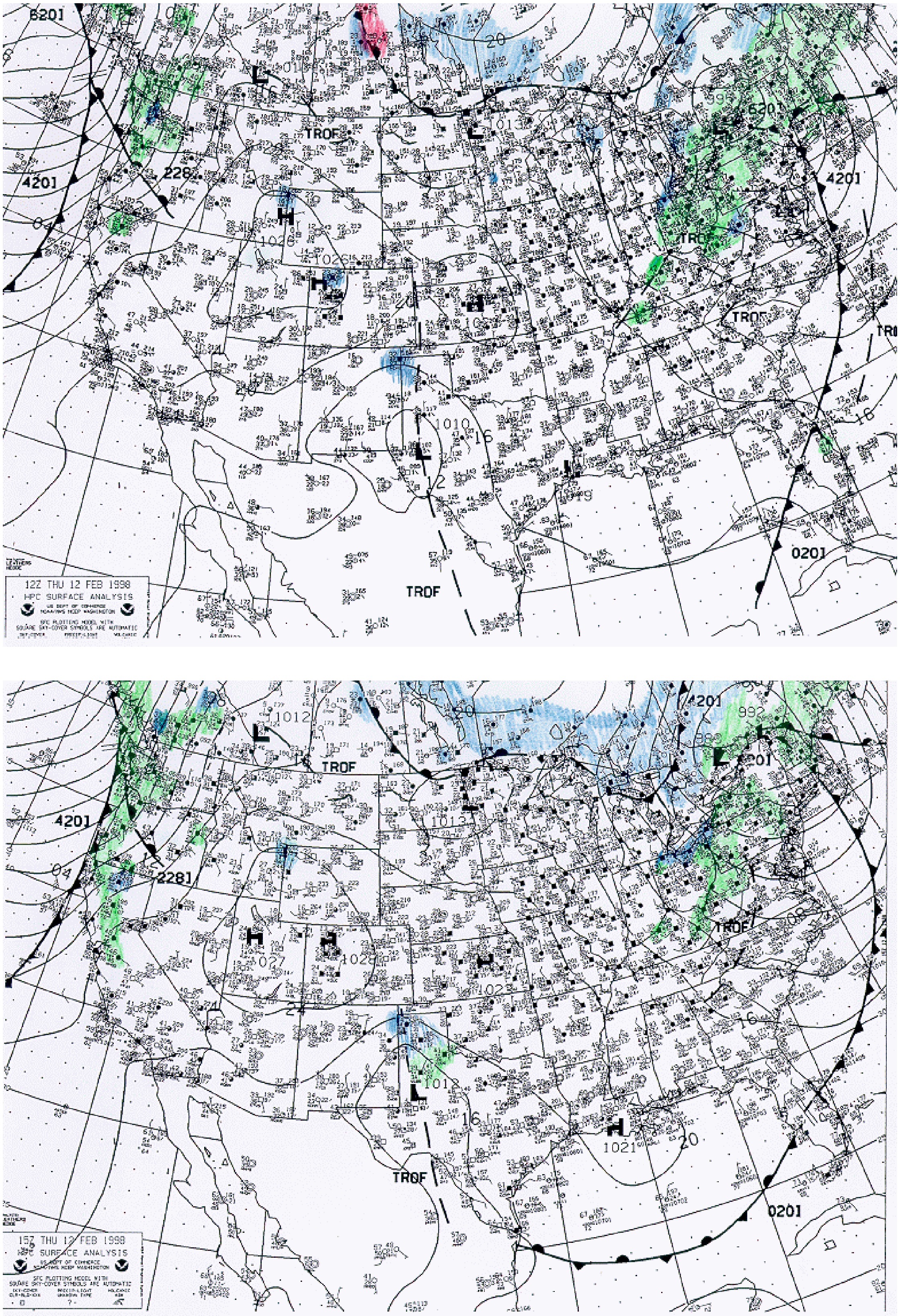


Figure 2 – Surface charts for 980212, a) 1200 and b) 1500 UTC.

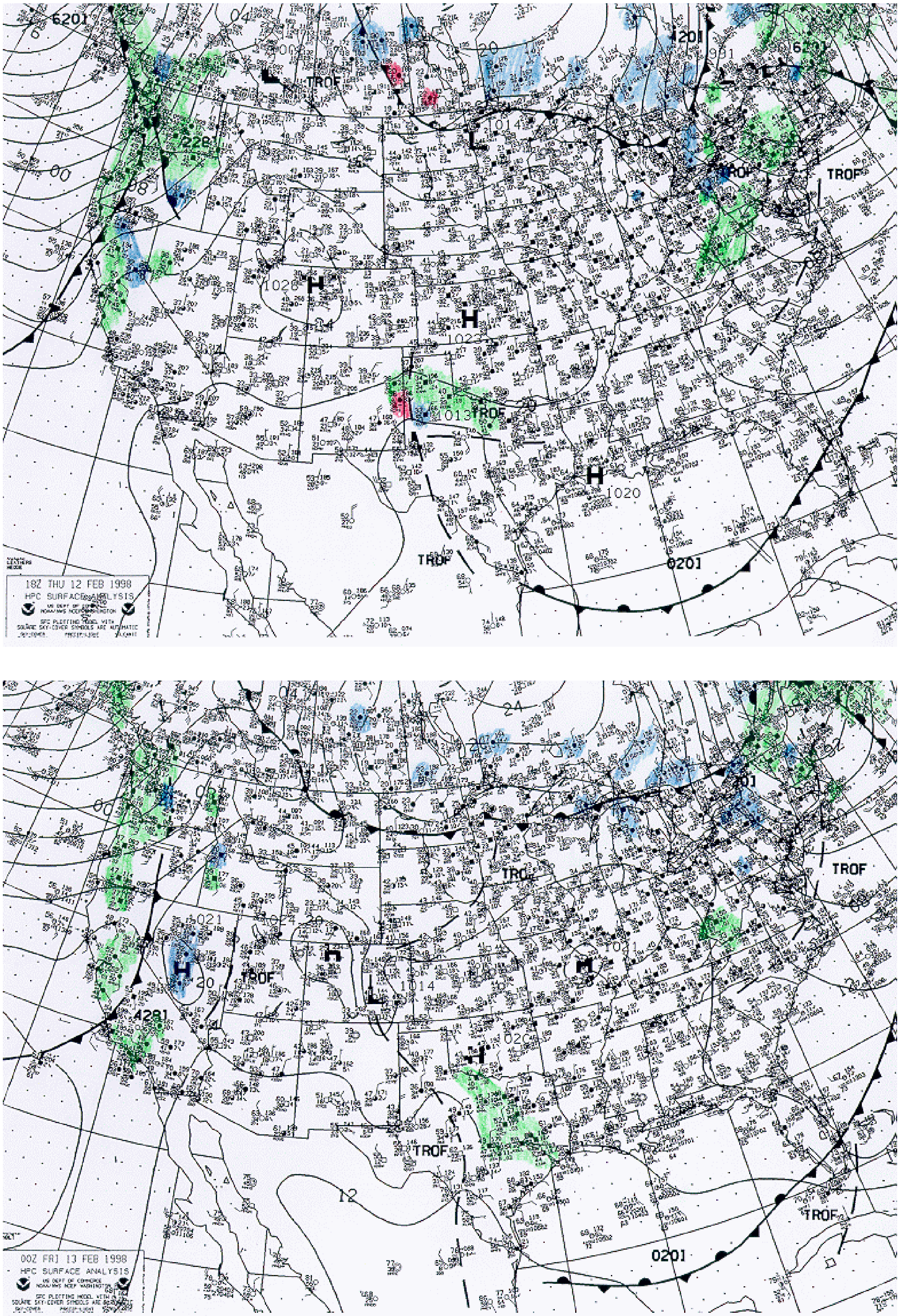
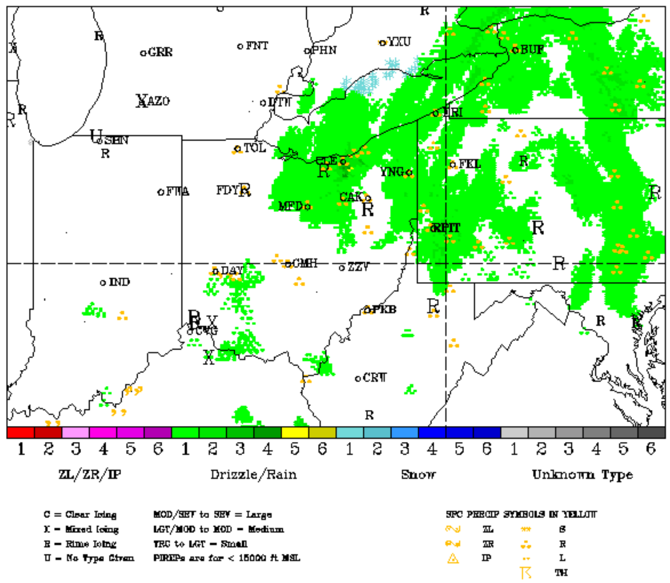


Figure 2 – Surface charts for a) 980212, 1800 and b) 980213, 0000 UTC.

RADAR DATA PLOT FOR 980212 AT 13 Z



RADAR DATA PLOT FOR 980212 AT 16 Z

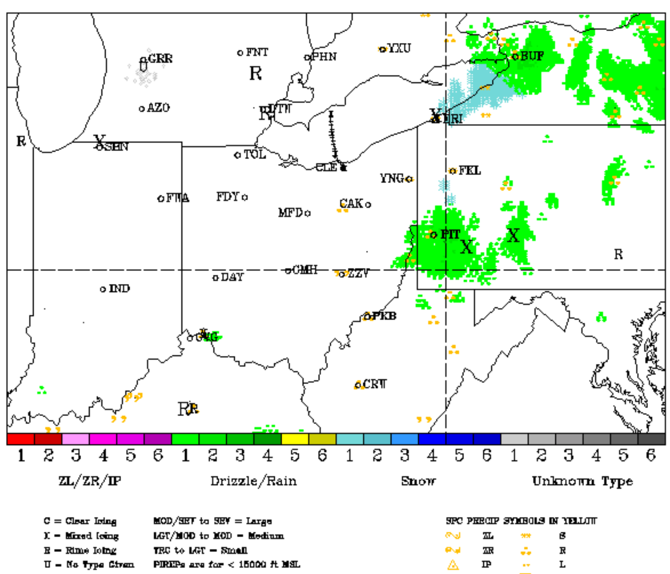
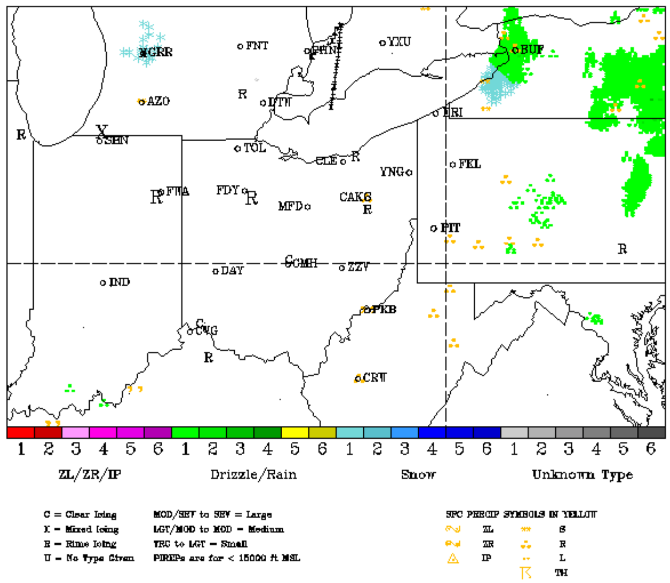


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980212, a) 1300 and b) 1600 UTC.

RADAR DATA PLOT FOR 980212 AT 17 Z



RADAR DATA PLOT FOR 980212 AT 18 Z

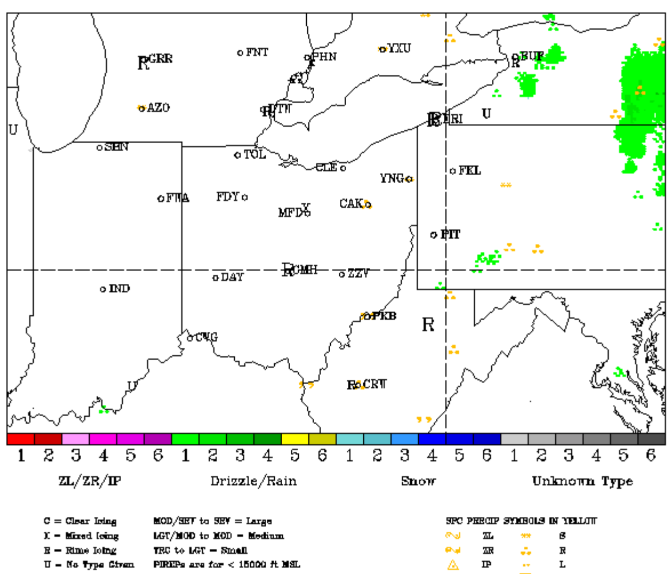
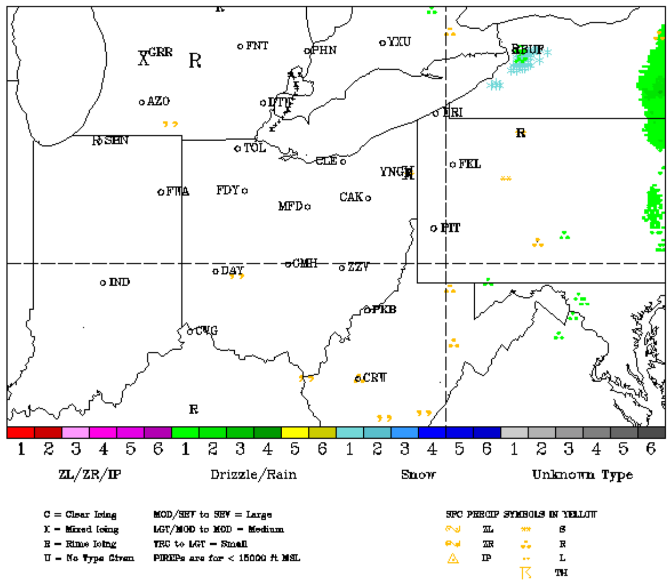


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980212, c) 1700 and d) 1800 UTC.

RADAR DATA PLOT FOR 980212 AT 19 Z



RADAR DATA PLOT FOR 980212 AT 20 Z

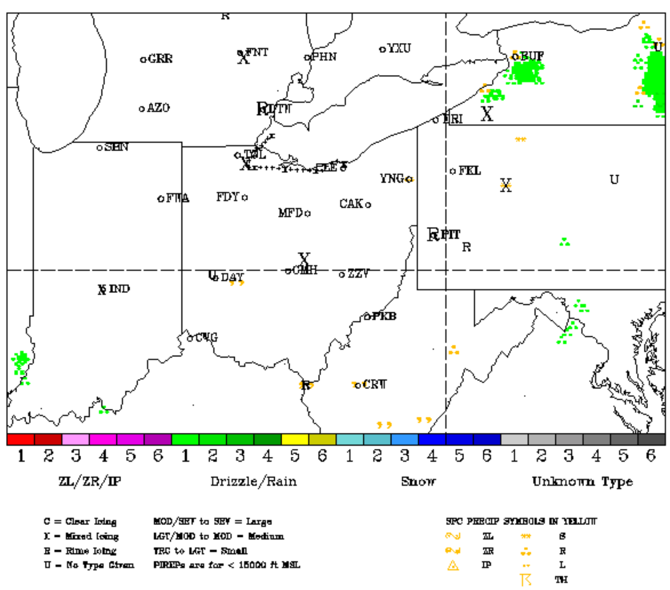
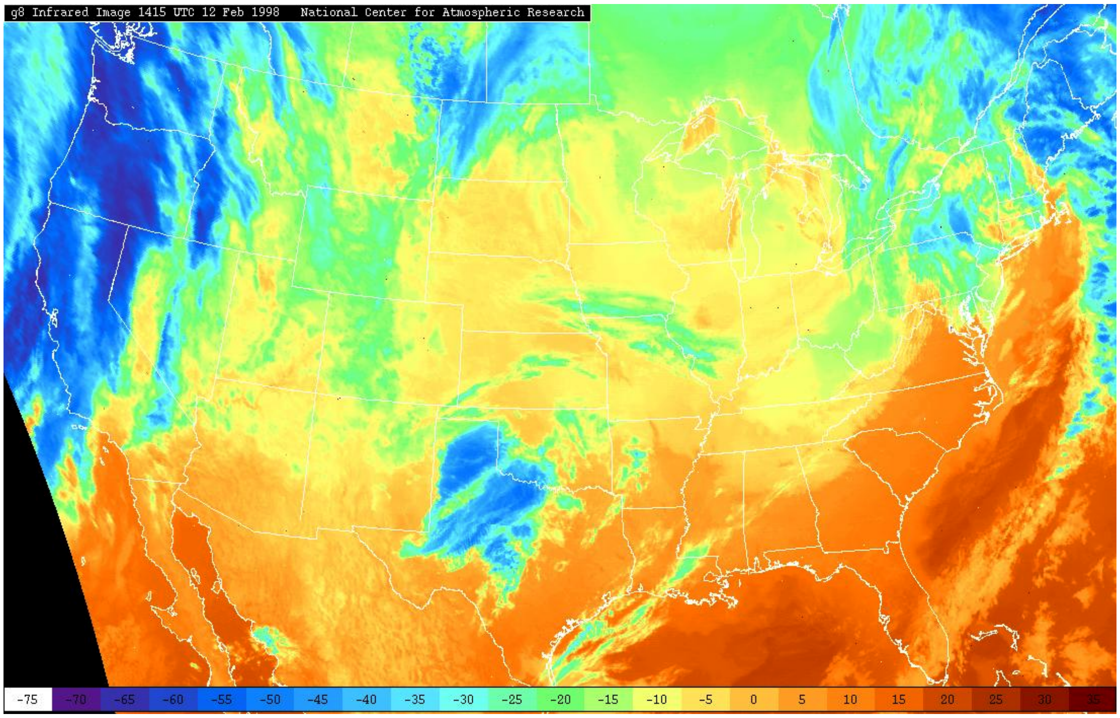


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980212, e) 1900 and f) 2000 UTC.



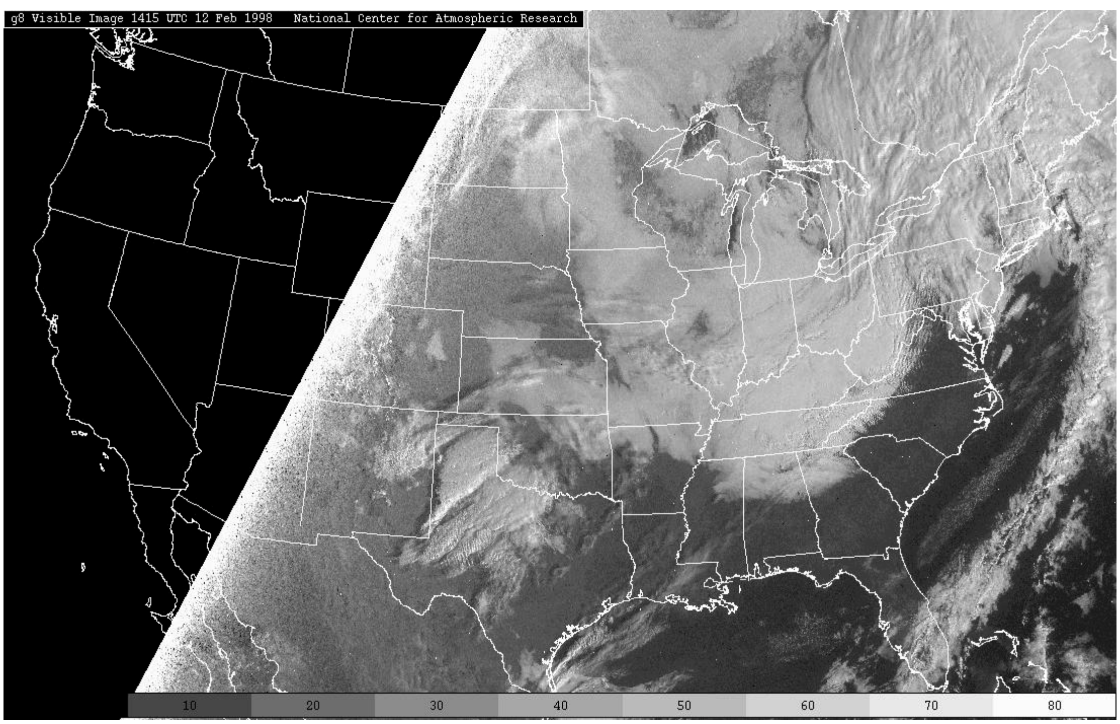
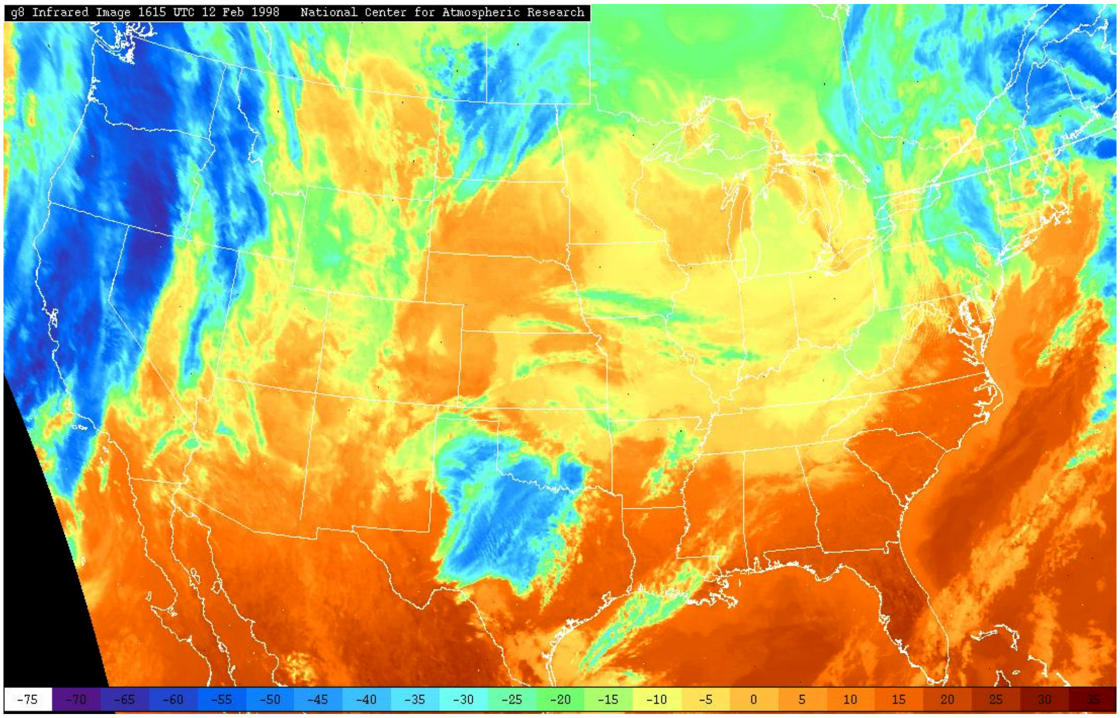


Figure 4 – GOES-8 a) infrared and b) visible satellite images for 980212, 1415 UTC.



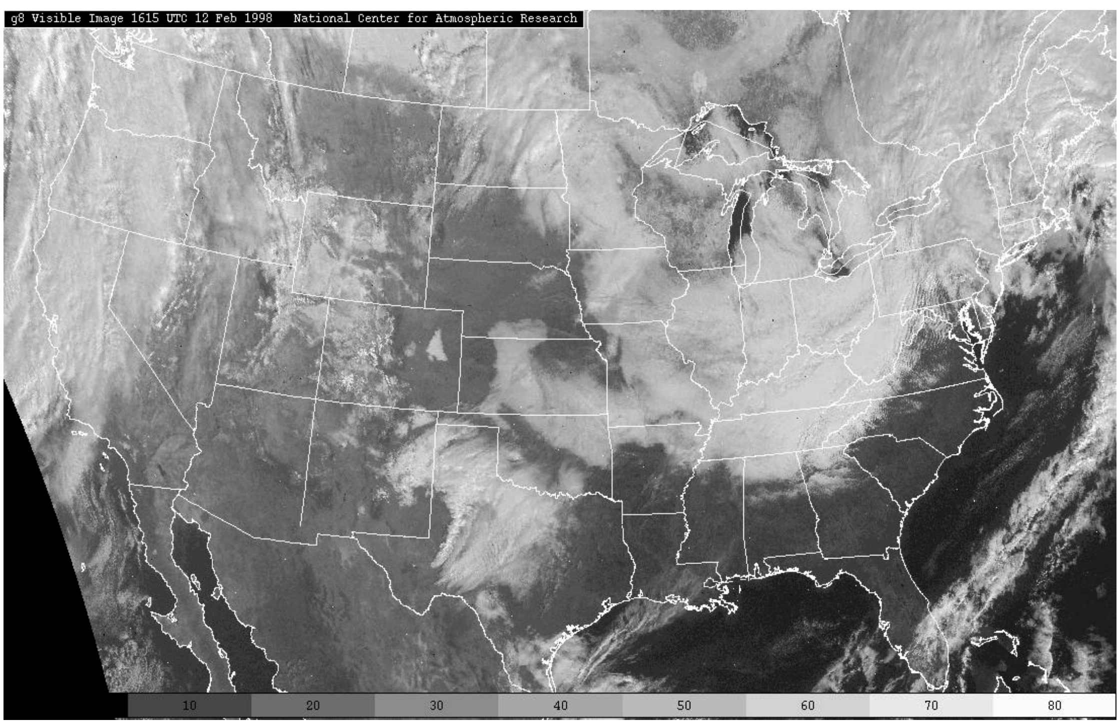
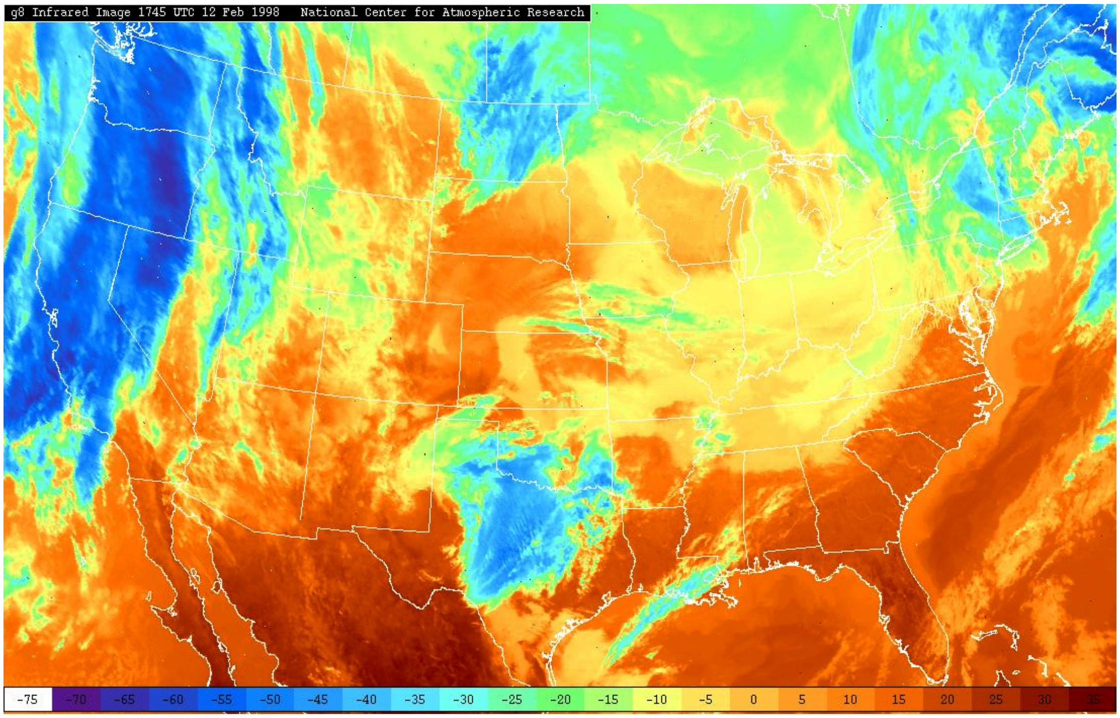


Figure 4 – GOES-8 c) infrared and d) visible satellite images for 980212, 1615 UTC.



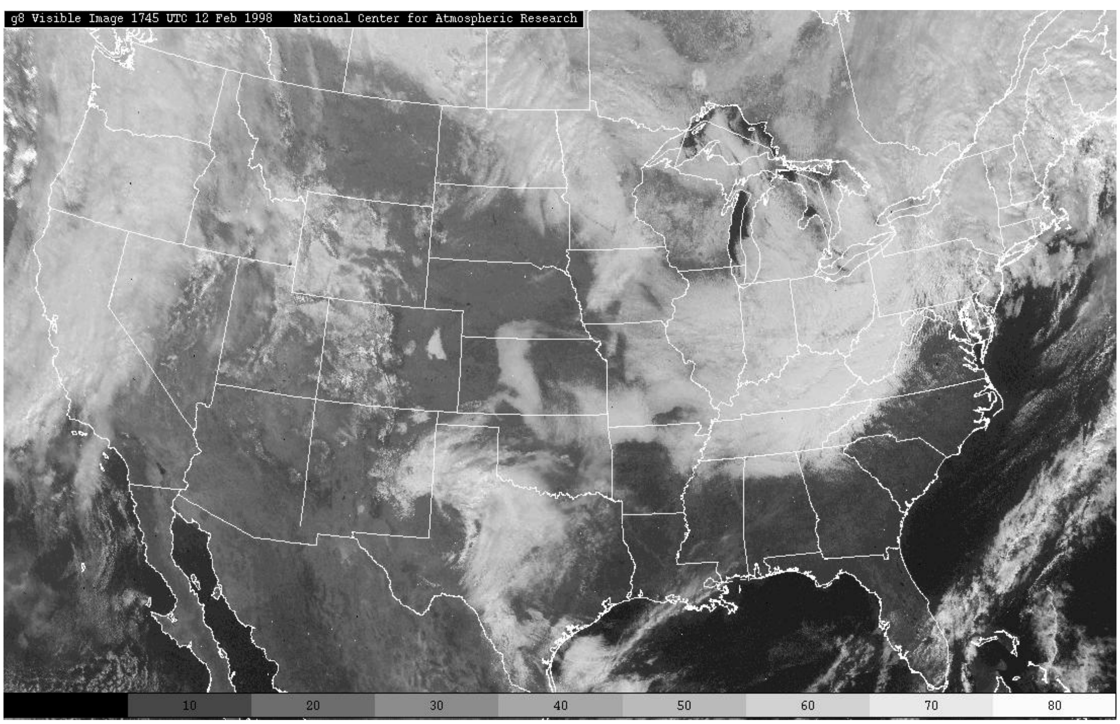
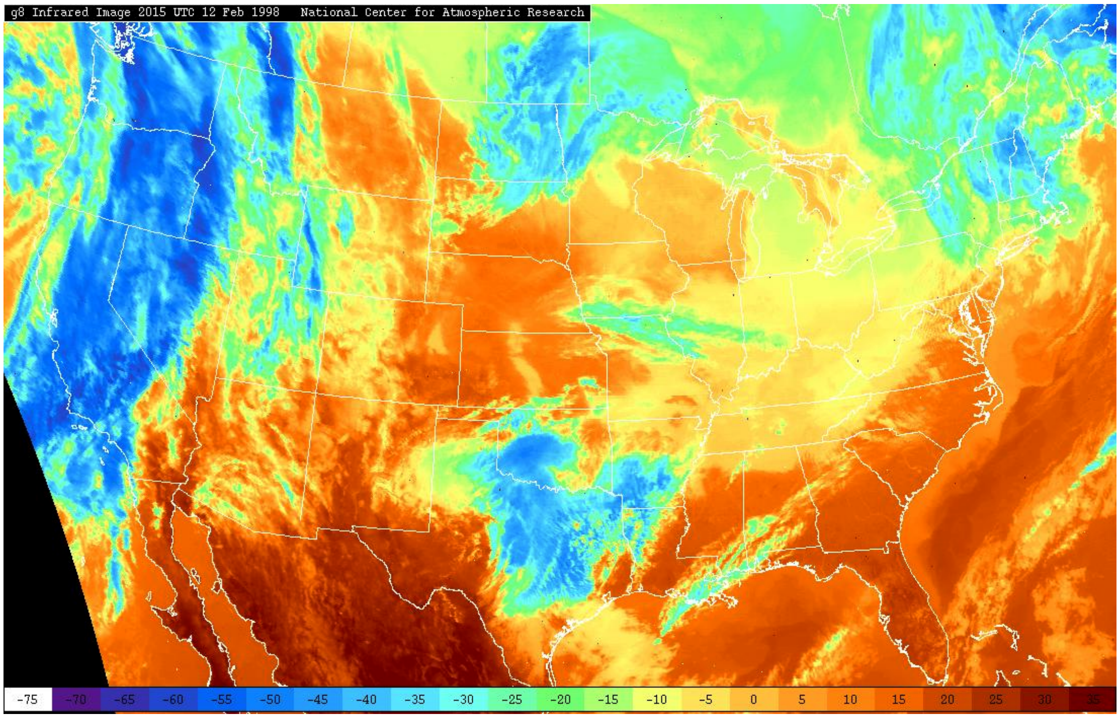


Figure 4 – GOES-8 e) infrared and f) visible satellite images for 980212, 1745 UTC.



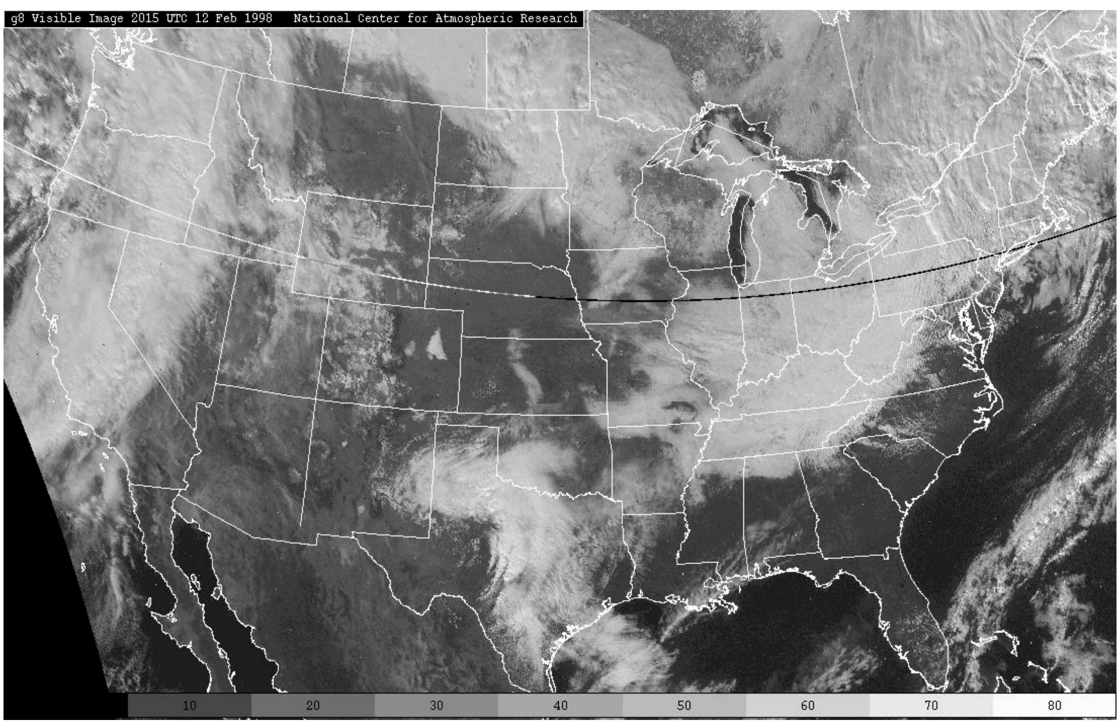


Figure 4 – GOES-8 g) infrared and h) visible satellite images for 980212, 2015 UTC.

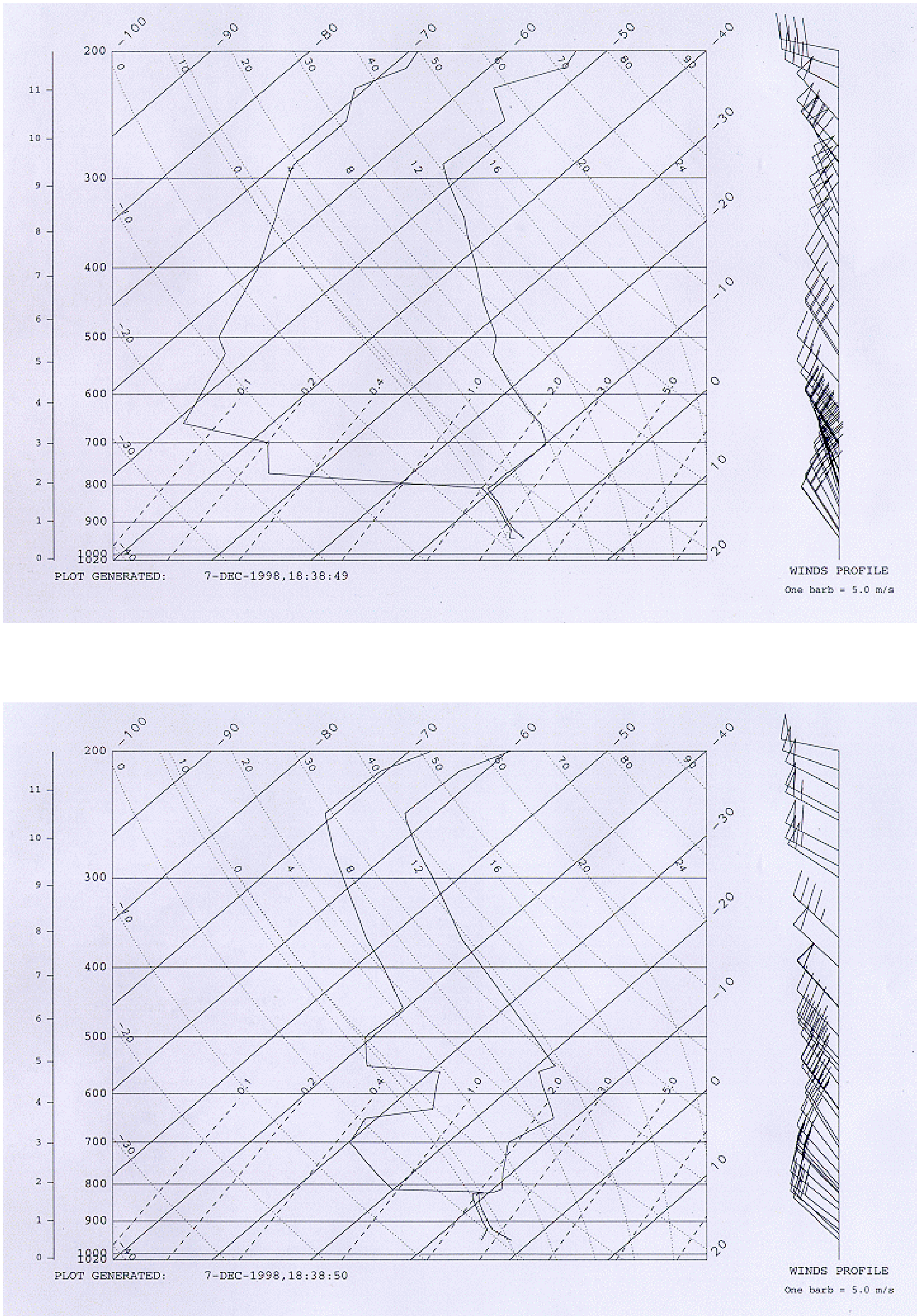
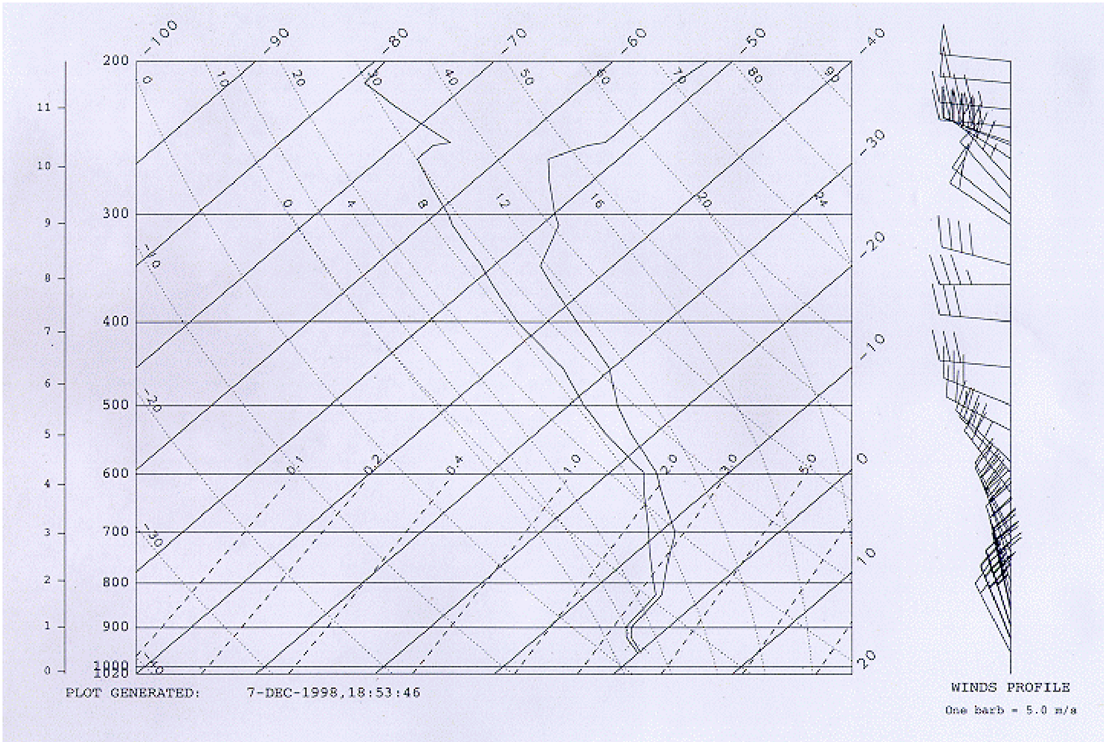


Figure 5 – Balloon-borne soundings from Alpena MI at a) 980212, 1200 and b) 980213, 0000 UTC.



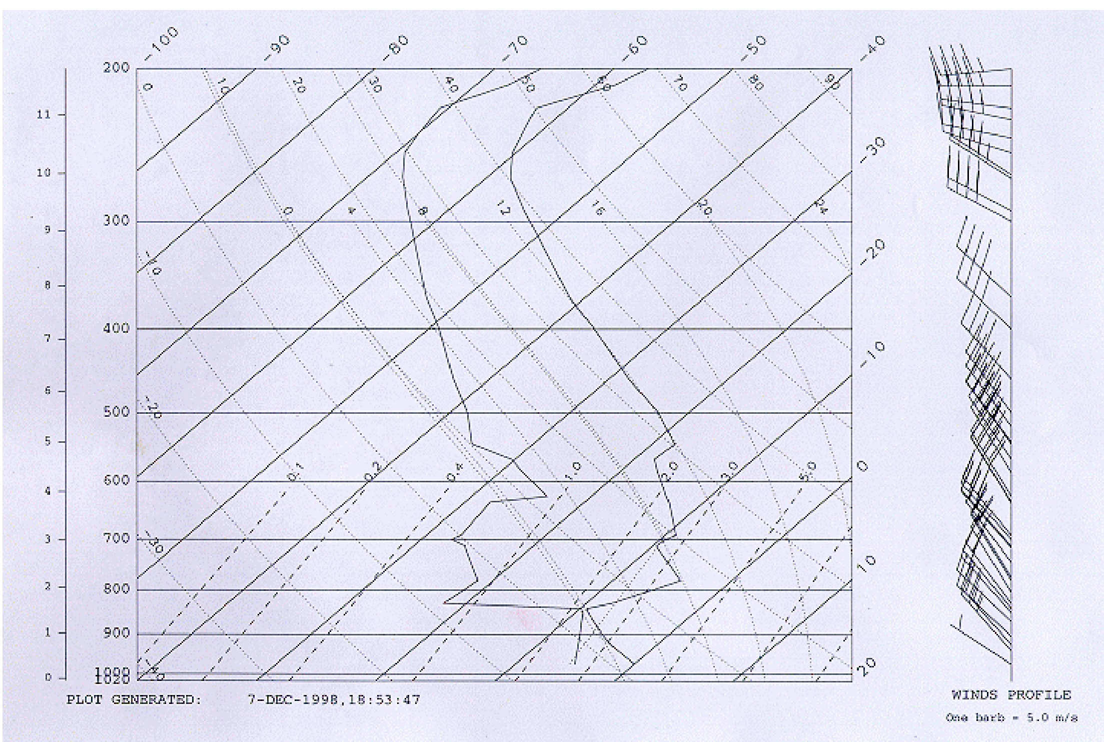
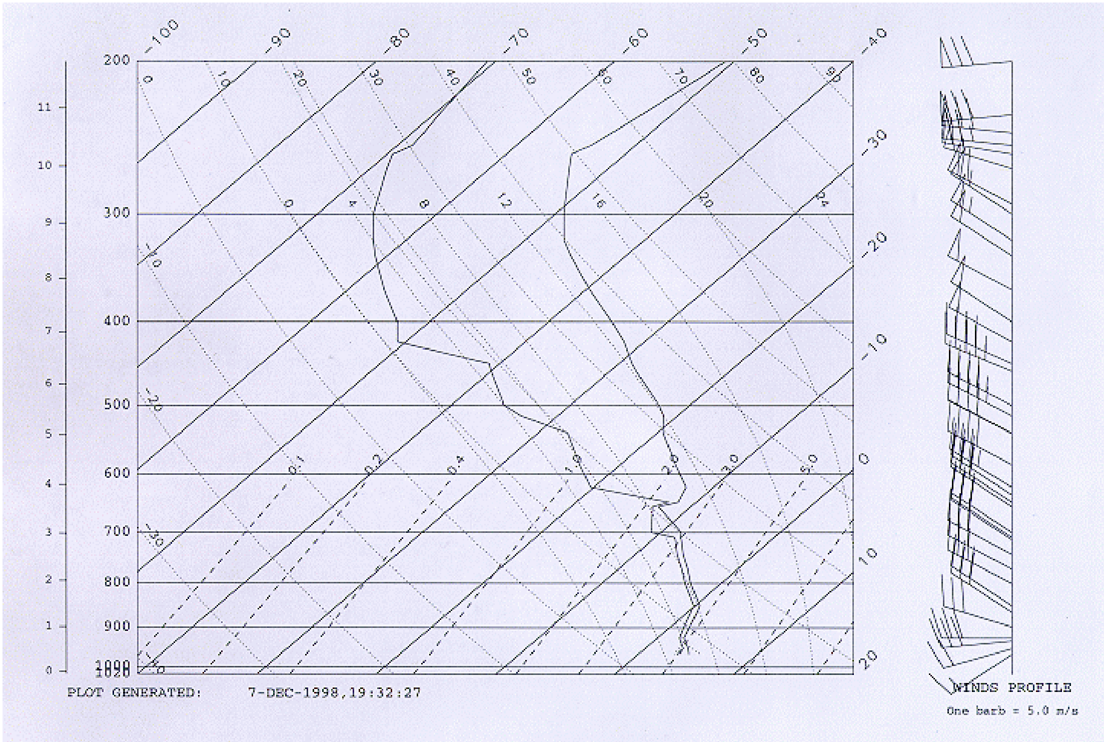


Figure 5 – Balloon-borne soundings from Detroit at c) 980212, 1200 and d) 980213, 0000 UTC.



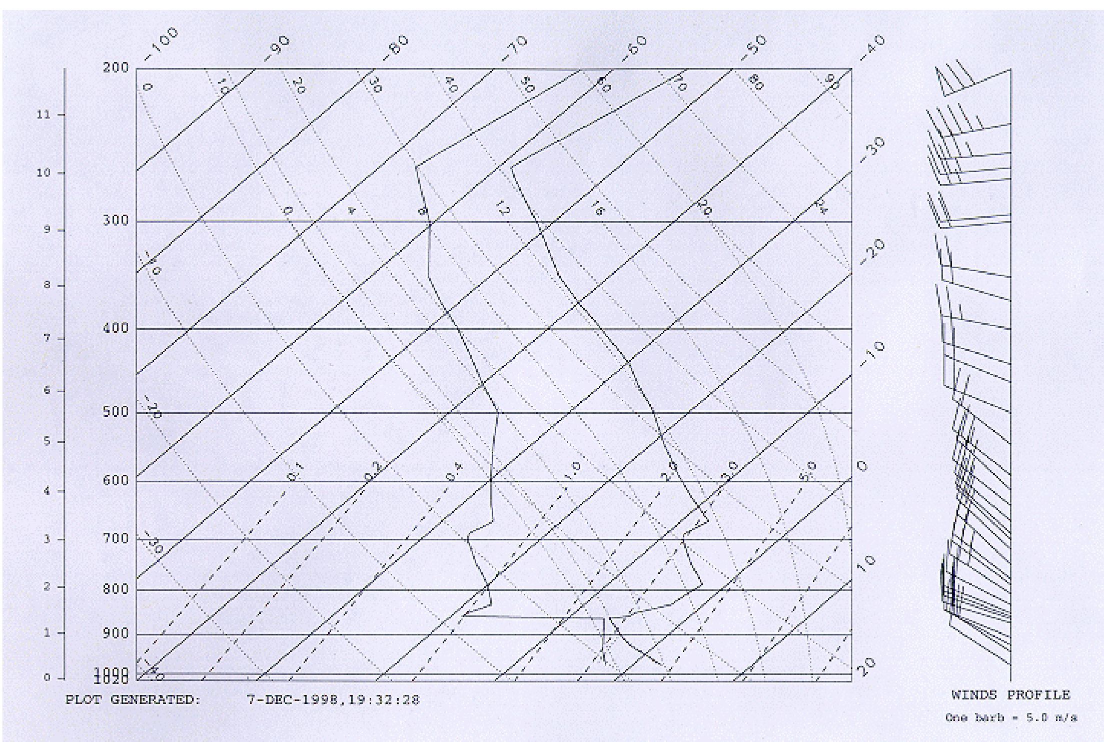
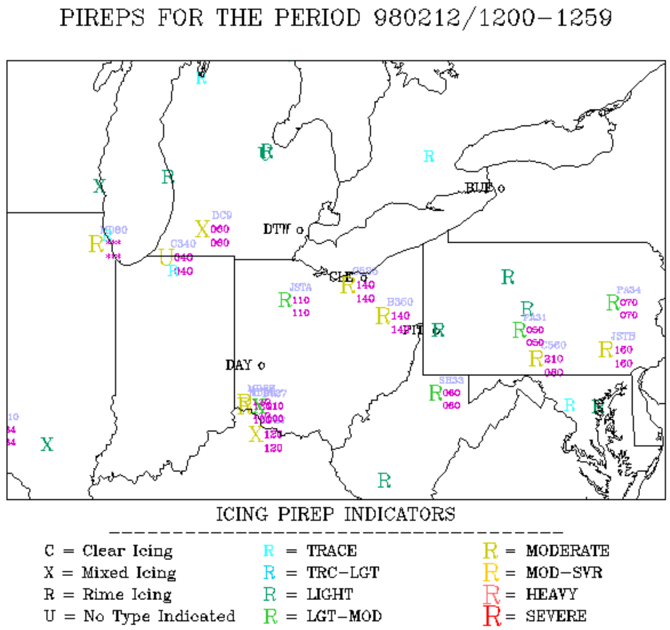


Figure 5 – Balloon-borne soundings from Wilmington at e) 980212, 1200 and f) 980213, 0000 UTC.



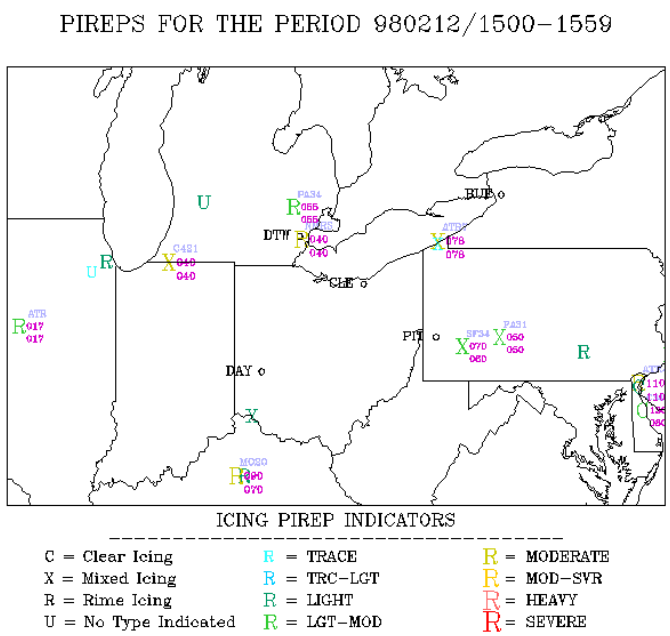
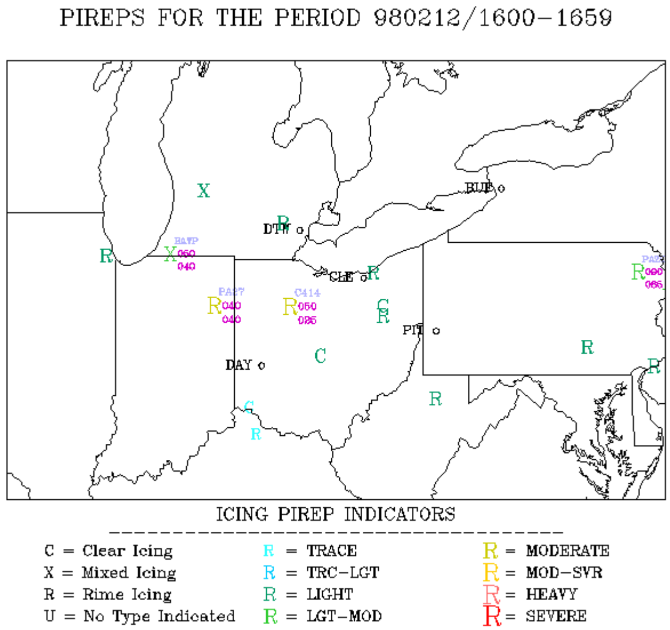


Figure 6 – Pilot reports of icing for 980212, a) 1200-1259 and b) 1500-1559 UTC.



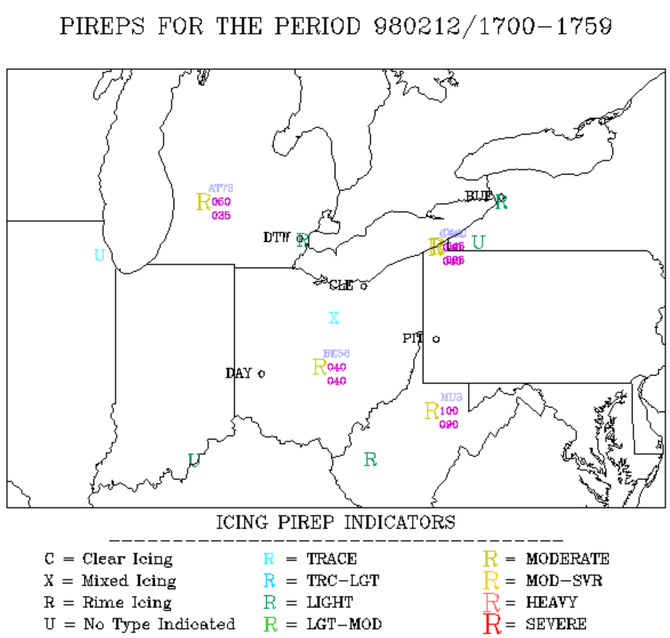
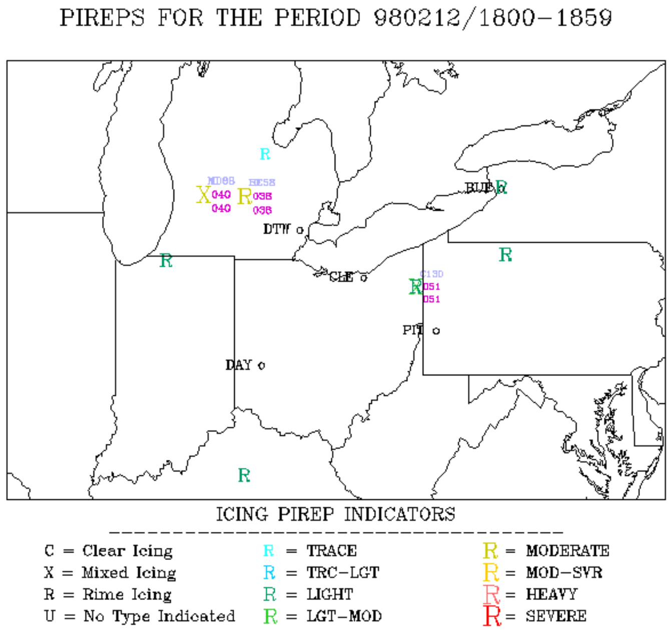


Figure 6 – Pilot reports of icing for 980212, c) 1600-1659 and d) 1700-1759 UTC.



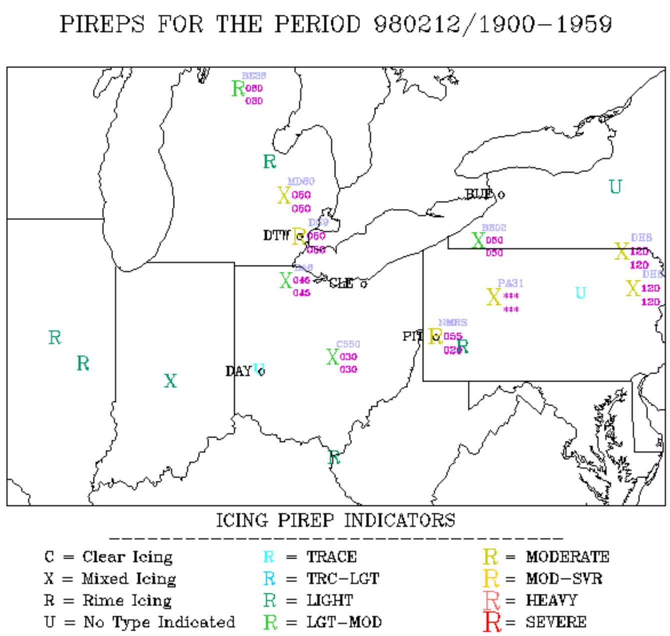


Figure 6 – Pilot reports of icing for 980212, e) 1800-1859 and f) 1900-1959 UTC.

February 19, 1998

Flight #1—Over Cleveland, Youngstown, and Canton-Akron, OH, from 1316 to 1503 UTC.
Flight #2—Over Canton-Akron and Cleveland, OH, from 1619 to 1658 UTC.

Brief overview

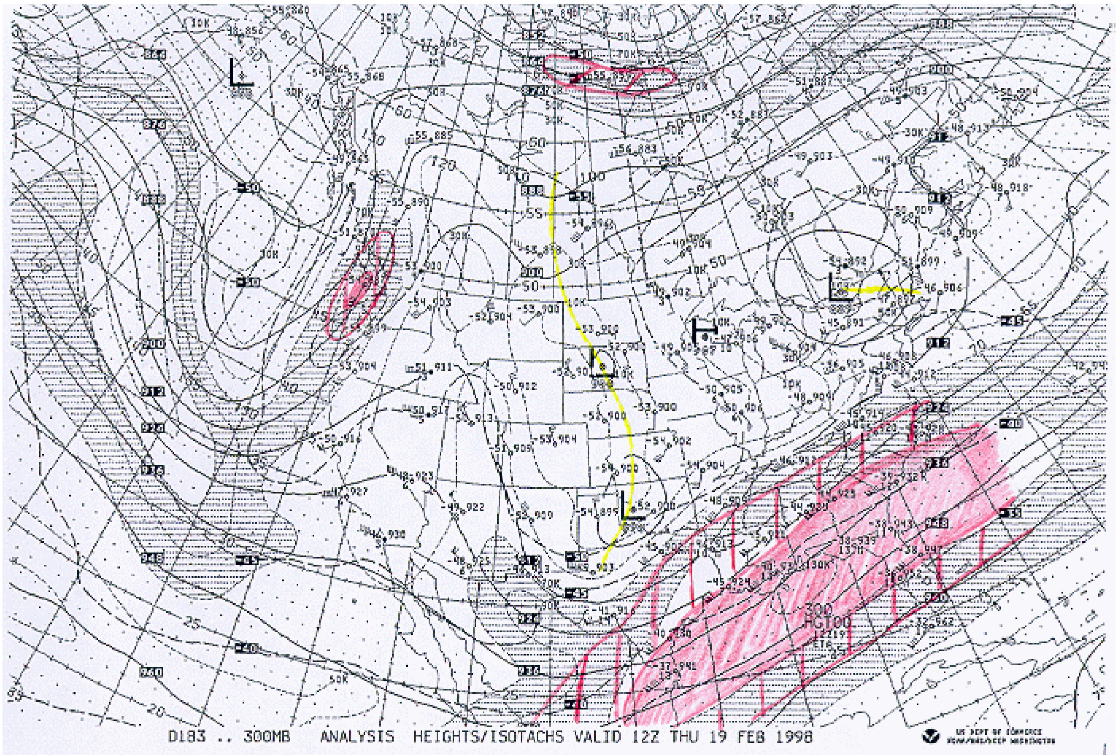
On this day, two flights were made into a low altitude, very warm cloud deck comprised of small-droplets and some drizzle (L) and freezing drizzle (ZL), and a colder upper cloud deck that contained small-droplet and mixed-phase conditions. Some snow was observed between the cloud decks, and temperatures near 0C were observed near the lower cloud tops, possibly indicating that melting may have played a role in the L/ZL formation early in the day. During the first flight, L was observed up to the freezing level (2400') on climbout toward the northeast from Cleveland. Some ZL was mixed in with cloud-sized drops above that (cloud base was 1800'). LWC increased to about 0.25 within these clouds, which had tops near 5600' and a CTT near 0C. Light snow was found from above this cloud to the base of the upper cloud deck at 9200'. A little bit of ZL may have been present at and below these cloud bases, while ice crystals were quite evident. The upper cloud deck had tops at 10,900', LWC up to 0.4, and a CTT of –11C. No precipitation was present above this deck. Flights around and soundings taken at Youngstown (YNG) and Canton-Akron (CAK) revealed similar cloud structures, temperatures and precipitation types. Some ZL seemed to be present beneath the upper cloud deck (mixed with snow, T = -7.5C), and near the base of the lower cloud deck (T = -1C) at these locations. A solid cloud layer with LWC up to 0.7 (T near -1C) was present between 1400' and 3800' over CAK.

During the return flight to Cleveland, the lower, all-liquid cloud was sampled. No ice crystals were discovered during a brief stint at 7000'. This points to a collision-coalescence formation process for the L and warm ZL that was observed within and below this cloud deck during the second flight. LWC was as high as 0.8 (at 4000'), the cloud deck extended from 1700' to variable tops between 4900' and 6000', and had CTTs near –1C.

Relevant weather features

At 1200 UTC, a 300 mb closed low was centered just to the north of Lake Ontario, and a ridge ran from Indiana northwestward to Lake Superior (Fig. 1). This pattern continued at 500 mb, but the low was slightly stronger and directly over Lake Ontario. Troughs ran to the east and northwest from the low, and moist air was primarily found along and to the north of these features. Very dry air and cold advection existed across Michigan, Ohio, and the mid-Atlantic states. Saturated air extended much further to the south at 700 mb, covering the entire forecast area. The low was more disorganized at this level, sprawling across the eastern Great Lakes. No significant temperature advection appeared to be present at 700 mb. Weak cold advection showed up again across Michigan and northeastern Ohio at 850 mb. The cold advection straddled a weak trough axis that ran along the northern borders of Indiana, Ohio, and Pennsylvania to a weak, closed low that was centered near Albany. Moisture was widespread at 850 mb.

The 1200 UTC surface map (Fig. 2) had the trough axis seen at 850 mb in roughly the same location. This feature was essentially stationary during the period of interest. Spotty light rain were present mostly along and to its south, as well as with a second trough across New York state. The western trough lost most of its definition over Ohio and Indiana by 1800 UTC. Radar plots (Fig. 3-radar plots with precipitation type were only available for 1500 and 1800 UTC; radar plots without precipitation type for 1300-1700 UTC are given in Fig. 4) show that the spotty precipitation dissipated during this period. The Twin Otter only flew into areas where no radar echoes greater than 18 dBZ were present. Some drizzle and rain was reported across the region, and light precipitation was sampled during the flights. Satellite data was only available for 1845 UTC (Fig. 5), more than one hour after the completion of the second flight. The visible and infrared images show widespread low clouds with CTTs of -5C to -15C topped by northwest-southeast oriented streaks of colder clouds. No sounding data was available for this case. Moderate severity mixed and rime PIREPs were abundant throughout the day, while clear PIREPs were prevalent before 1300 UTC (Fig. 6). Icing altitudes mostly ranged from 5,000 feet to 11,000 feet.



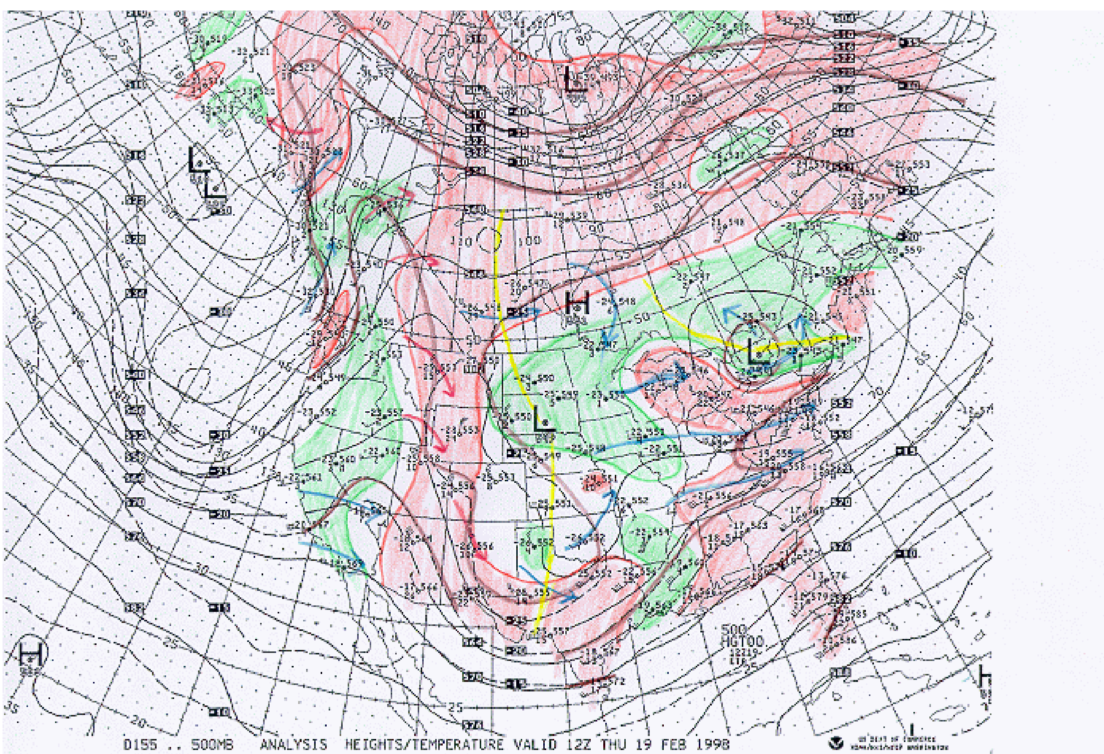
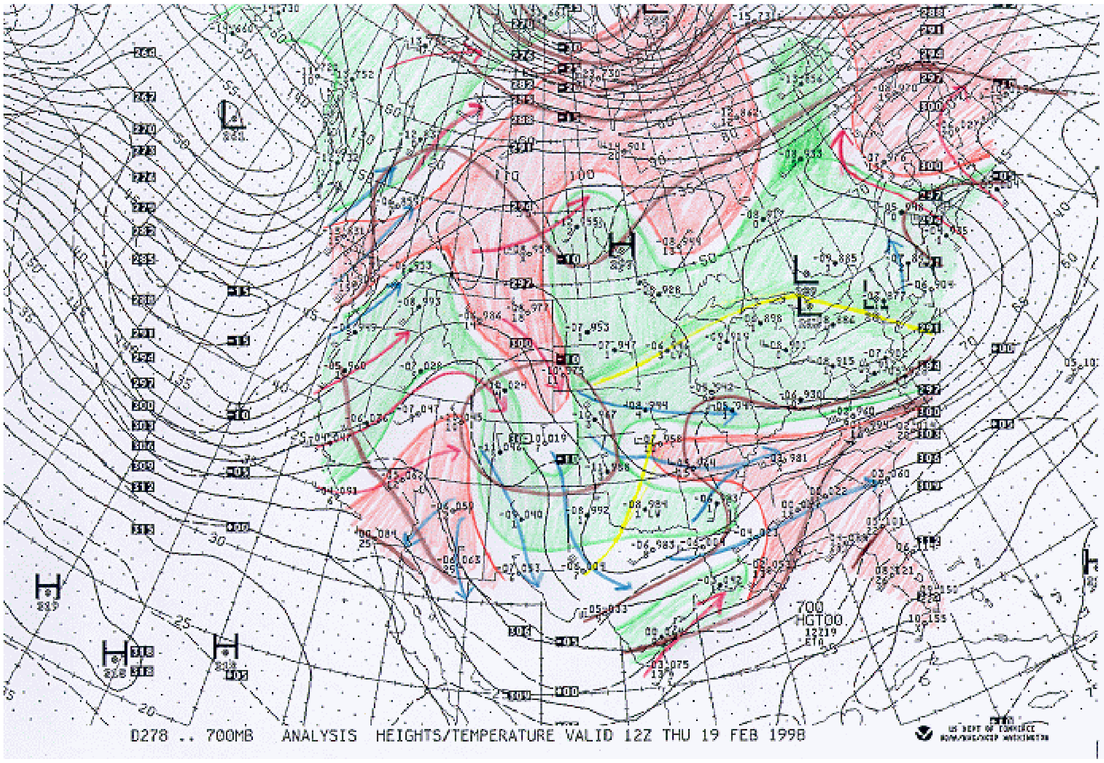


Figure 1 – Upper-air charts for 980219, 1200 UTC at a) 300 and b) 500 mb.



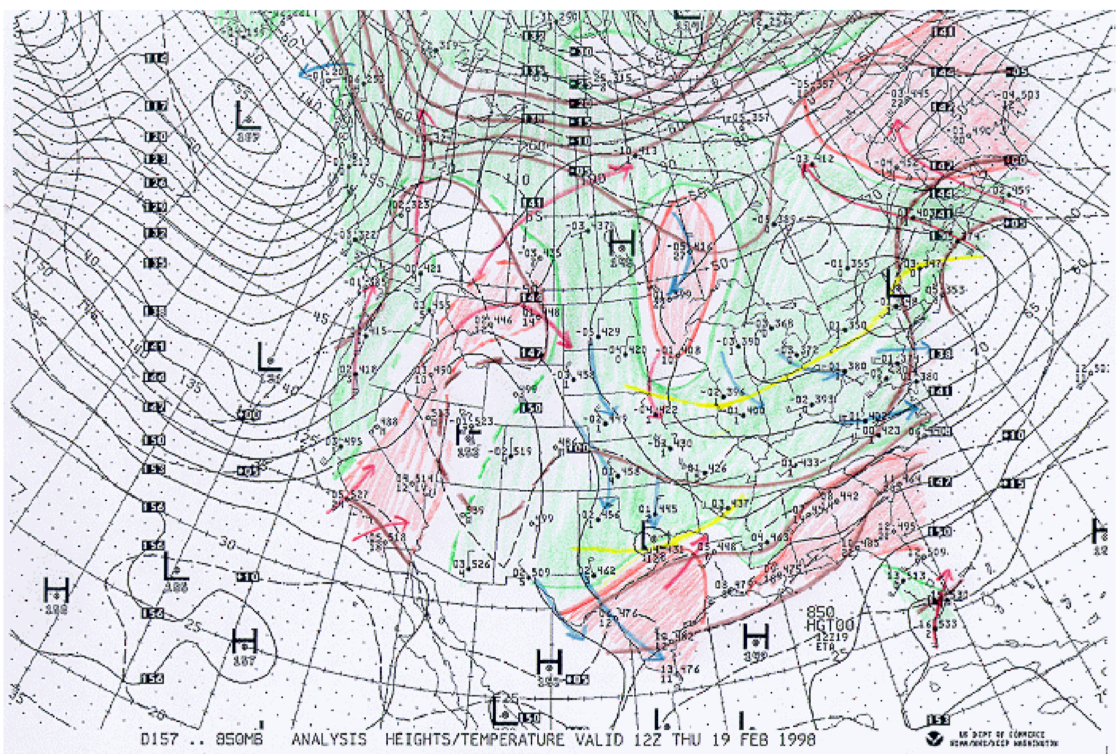


Figure 1 – Upper-air charts for 980219, 1200 UTC at c) 700 and d) 850 mb.

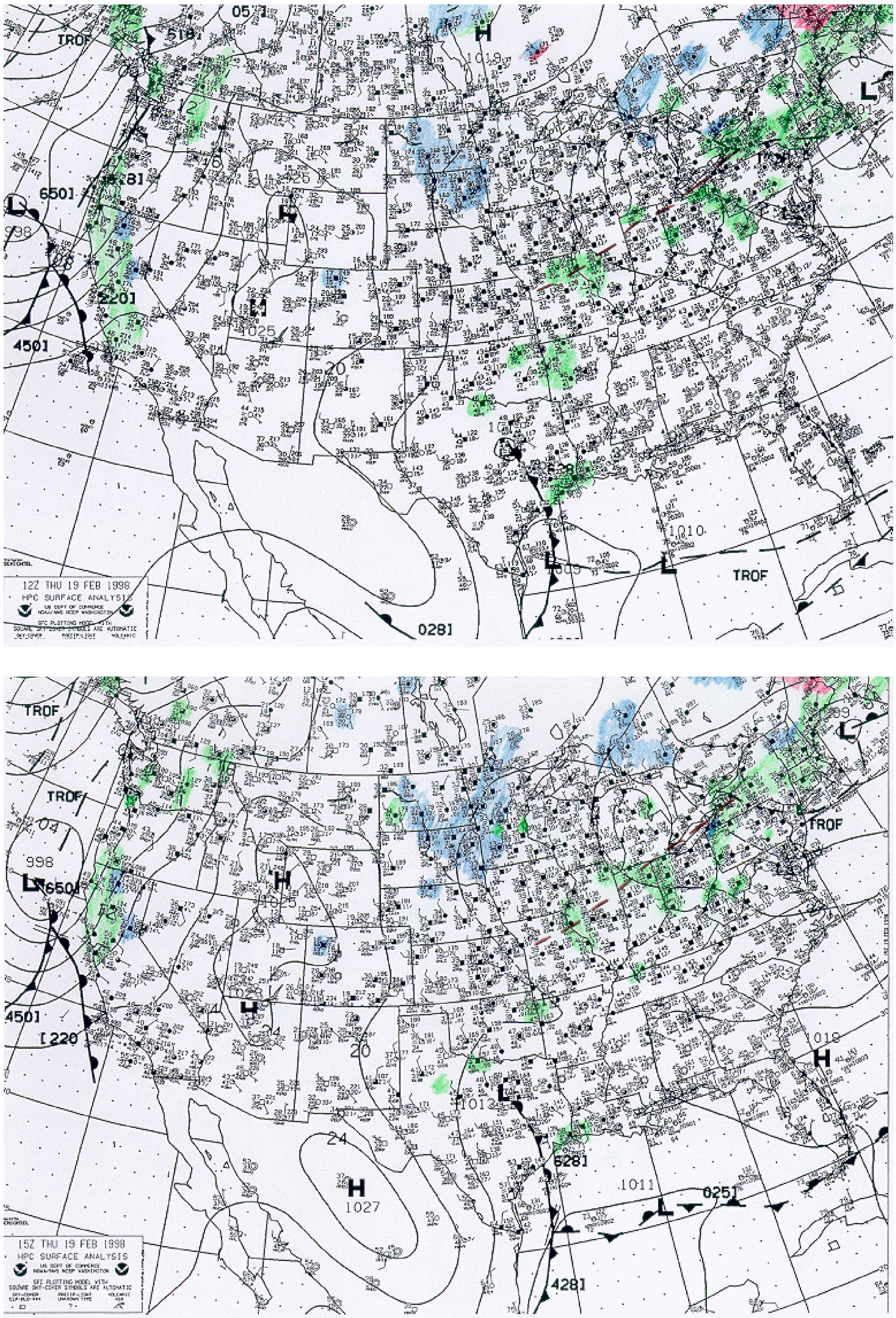


Figure 2 – Surface charts for 980219, a) 1200 and b) 1500 UTC.

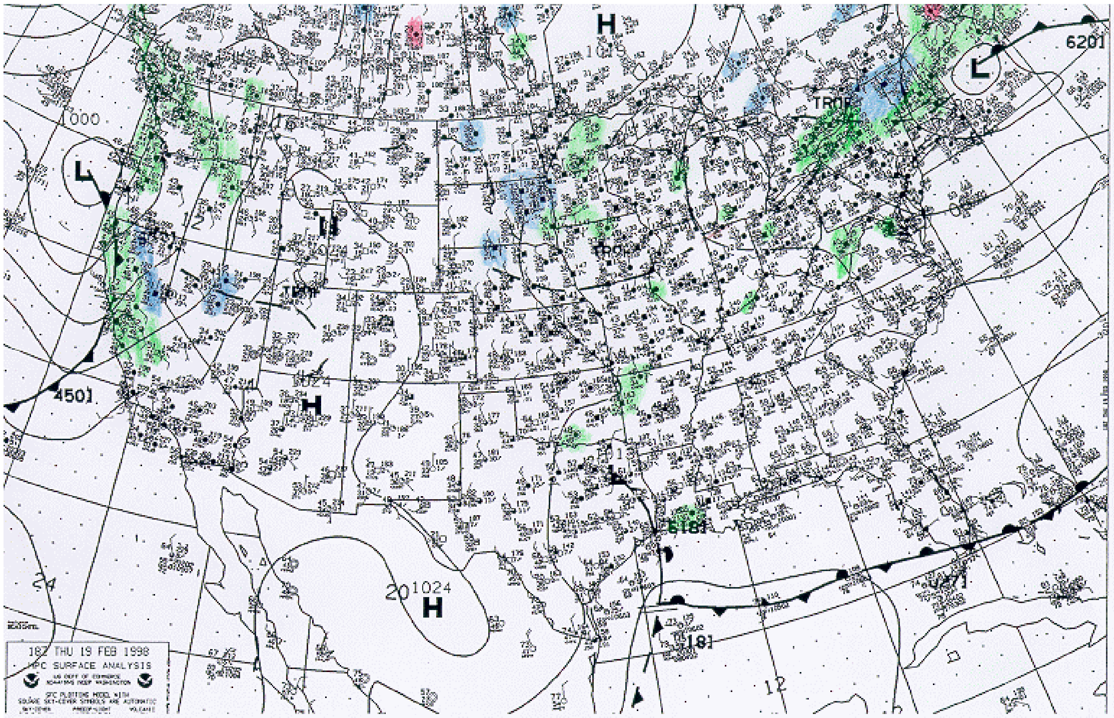
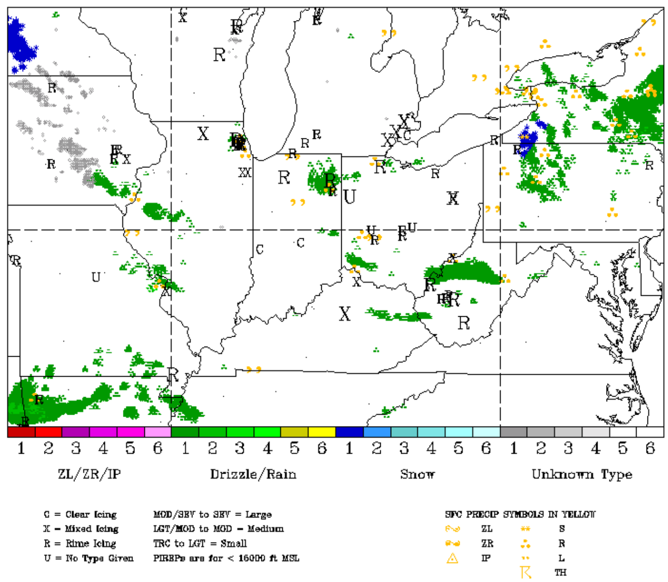


Figure 2 – Surface charts for 980219, c) 1800 UTC.

RADAR DATA PLOT FOR 980219 AT 15 Z



RADAR DATA PLOT FOR 980219 AT 18 Z

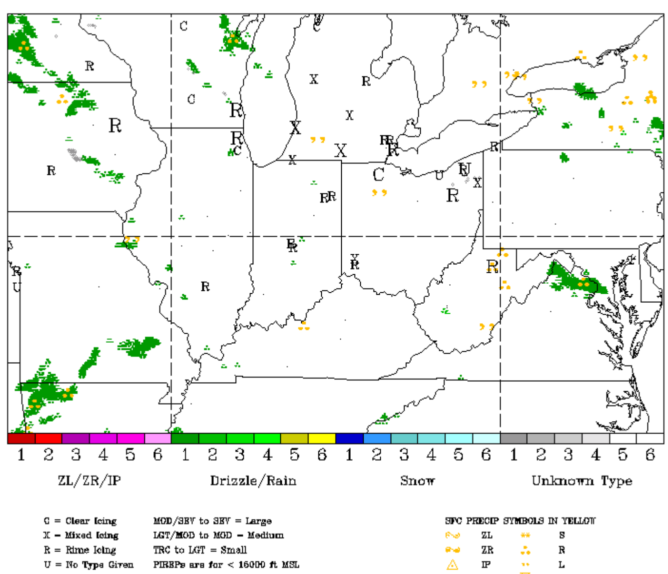
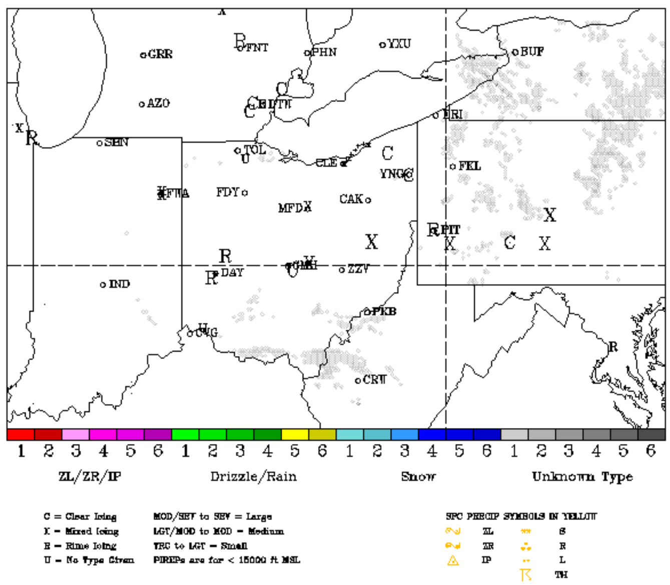


Figure 3 – Radar data, surface observations, and icing PIREPs for 980219, a) 1500 and b) 1800 UTC.

RADAR DATA PLOT FOR 980219 AT 13 Z



RADAR DATA PLOT FOR 980219 AT 14 Z

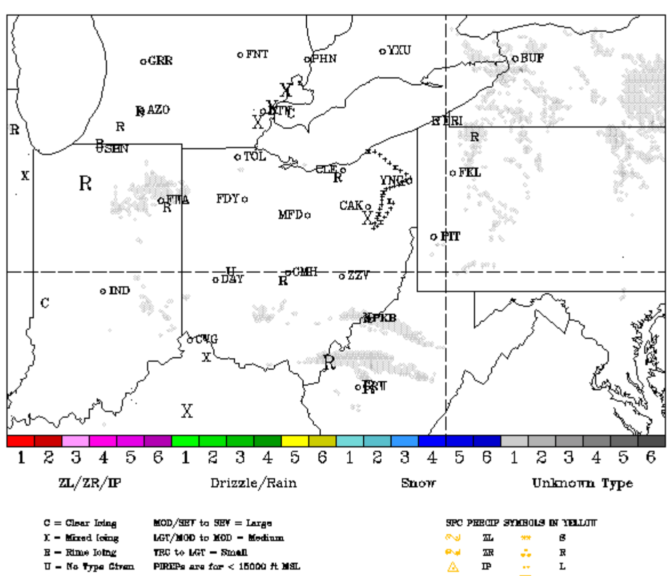
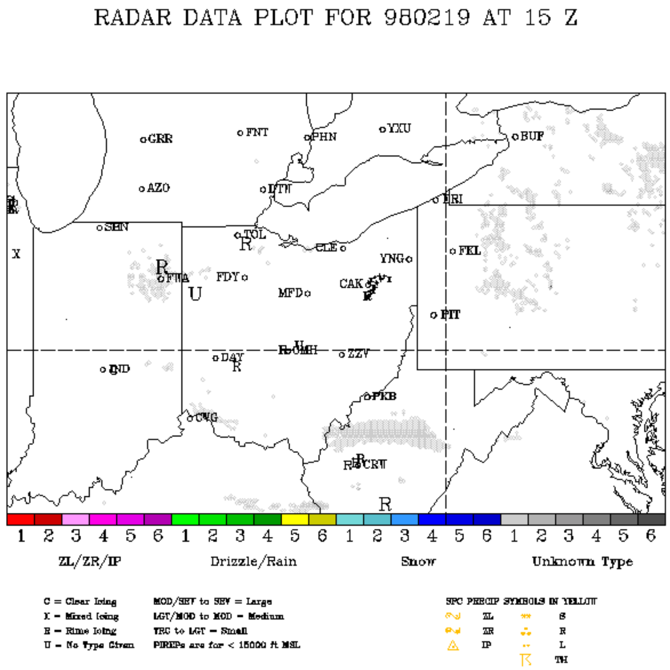


Figure 4 – Radar data, Twin Otter tracks, and icing PIREPs for 980219, a) 1300 and b) 1400 UTC.



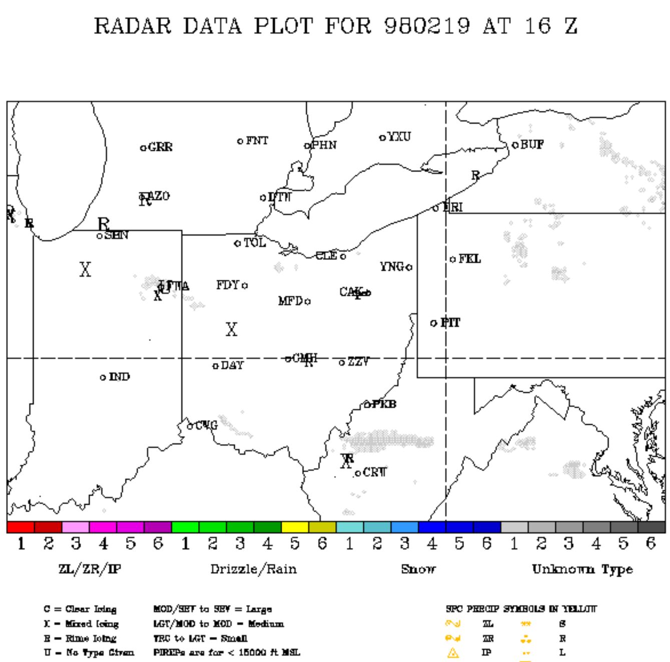


Figure 4 – Radar data, Twin Otter tracks, and icing PIREPs for 980219, c) 1500 and d) 1600 UTC.

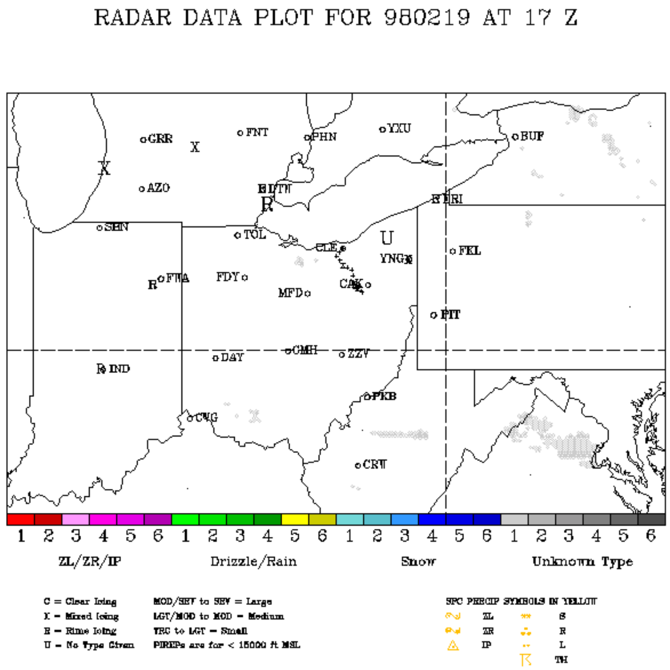
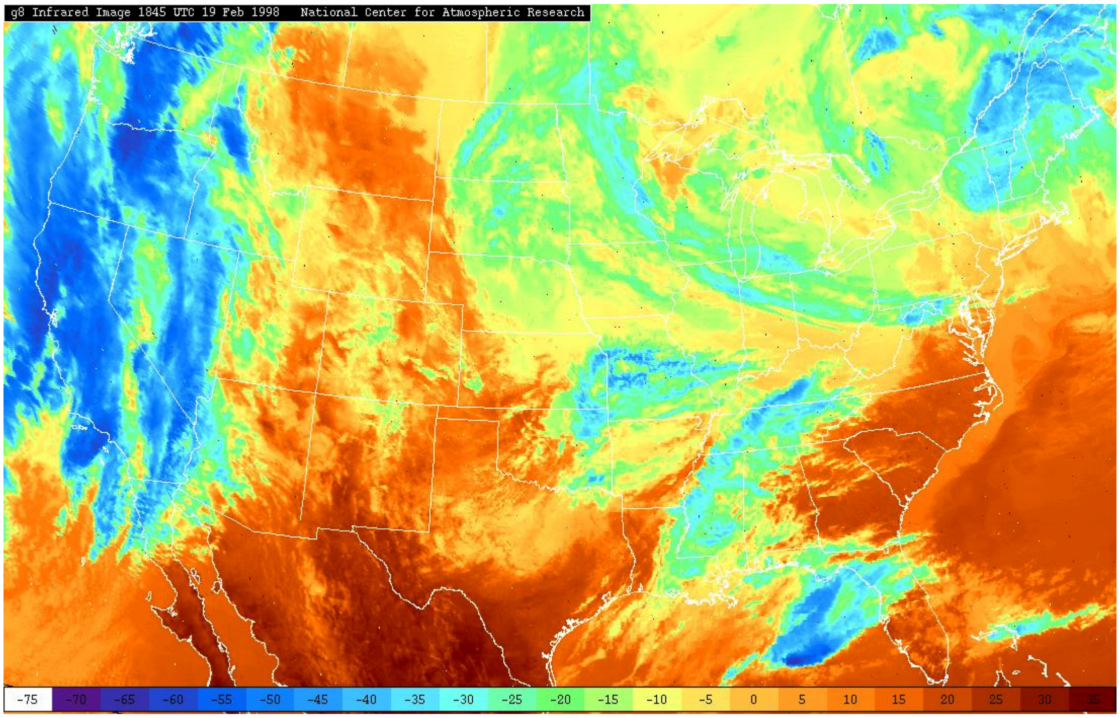


Figure 4 – Radar data, Twin Otter tracks, and icing PIREPs for 980219, e) 1700 UTC.



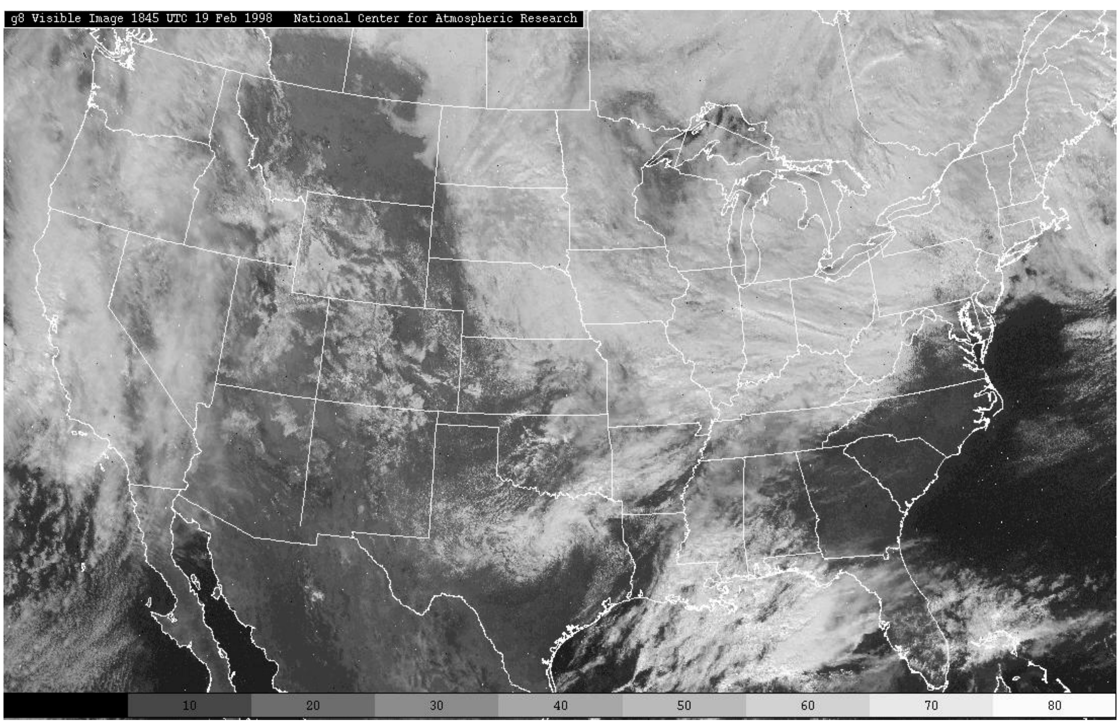
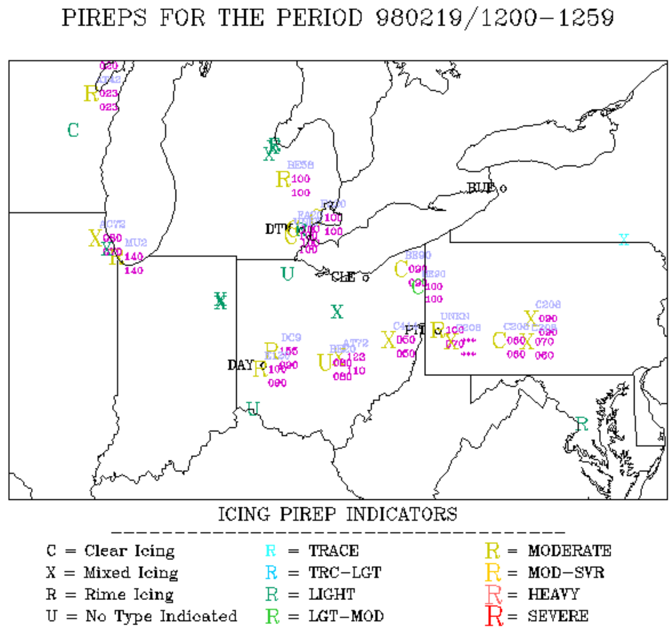


Figure 5 – GOES-8 a) infrared and b) visible satellite images for 980219, 1845 UTC.



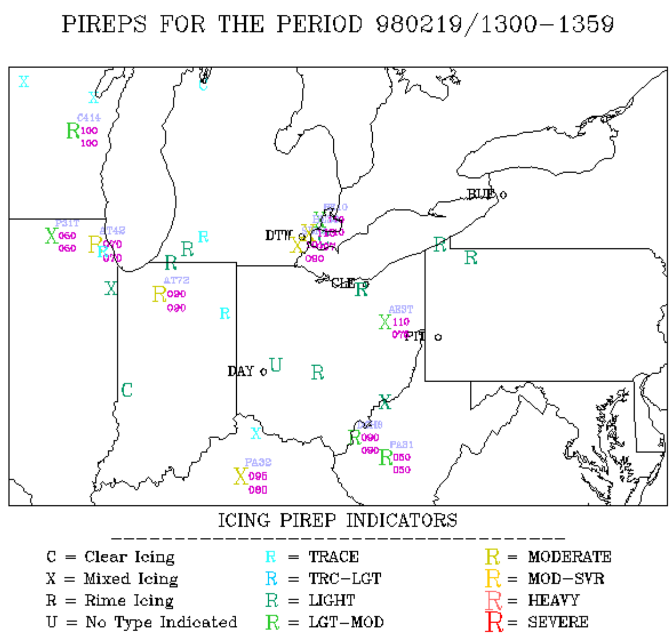
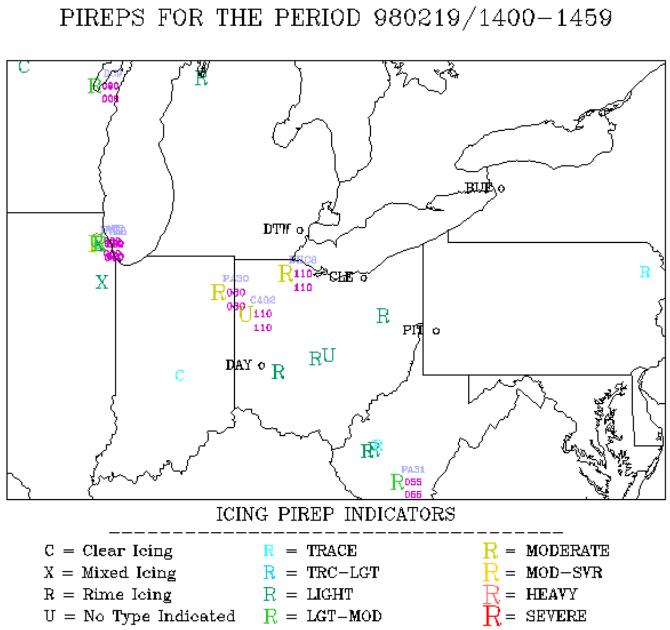


Figure 6 – Pilot reports of icing for 980219, a) 1200-1259 and b) 1300-1359 UTC.



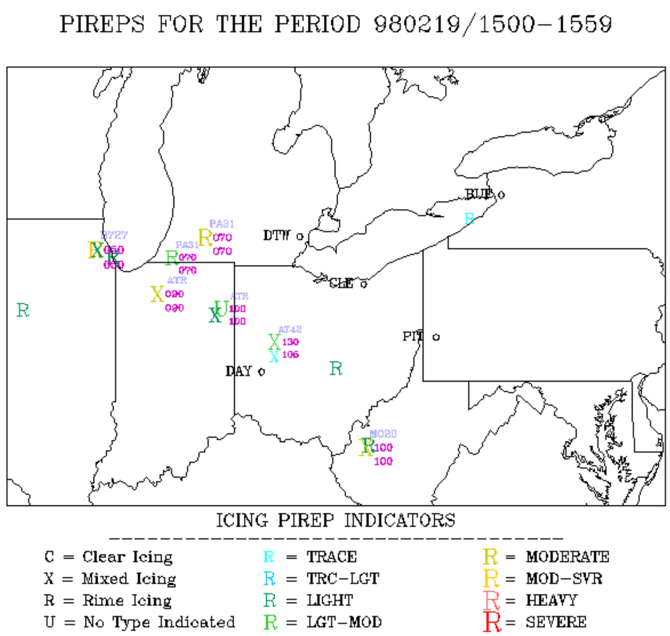
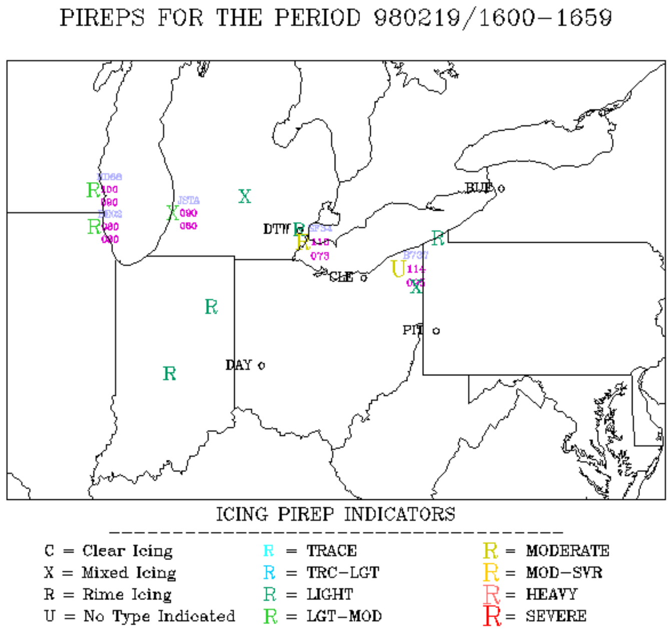


Figure 6 – Pilot reports of icing for 980219, c) 1400-1459 and d) 1500-1559 UTC.



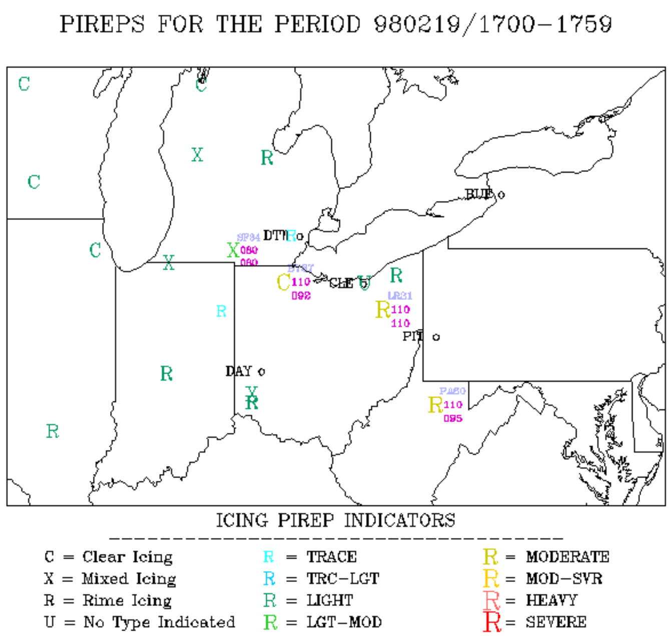


Figure 6 – Pilot reports of icing for 980219, e) 1600-1659 and f) 1700-1759 UTC.

February 24, 1998

Flight #1—Over Findlay and Columbus, OH, from 1330 to 1521 UTC.
Flight #2—Between Columbus and Cleveland, OH, from 1655 to 1751 UTC.

Brief overview

Two flights were made into a swath of clouds and precipitation that moved eastward across Ohio. During the first flight, shallow, small-droplet clouds were observed over Cleveland between 1700' and 2500'. These clouds were quite warm (CTT = -3C), and contained LWC up to 0.3. No clouds were observed above them as the Twin Otter ascended to 11,000' then flew westward at 8000'. Clouds and precipitation were first encountered at this altitude along the eastern edge of the approaching system. The leading edge consisted of 0.4+ LWC and freezing drizzle (ZL) at T = -6C. As the aircraft penetrated the heart of the precipitation swath, these particles became mixed with ice crystals. Snow concentrations increased and LWC decreased with further penetration. The LWC had a wavy pattern to it, with fluctuations on the order of 0.2. These fluctuations remained noticeable, and the mixture of cloud droplets, ZL, and ice crystals continued as the aircraft descended to 3000' over Findlay. A layer of above-freezing temperatures was present from 4400' to 4700', with a maximum temperature of +0.3C at 4500'. Subfreezing temperatures existed below that, and ZL mixed with ice crystals was observed within and below cloud base (3800') there. Cloud top heights and CTTs varied dramatically across the cloud and precipitation swath. Multiple cloud decks were evident in some places, but precipitation was typically present between decks. Consistent ZL, mixed with ice crystals, and more wavy LWC was observed near 8000' between Findlay and Columbus (CMH). Only small droplets mixed with ice crystals were observed upon descent into CMH.

Between flights, the precipitation swath passed over CMH. Thus, the beginning of the climb out of CMH was made on its western edge. Low LWC (<0.1) was found there, but the aircraft quickly entered the precipitation region, finding aggregates, columns/needles, stellars, and irregulars. Multiple cloud decks were observed again, with snow between the decks. Mixed conditions dominated, and LWC was not as high during this flight, with maximum values near 0.25. The ice crystals tapered off, then ended (and the small-drop liquid cloud ended soon thereafter) as the aircraft exited the eastern end of the precipitation swath on approach to Cleveland.

Relevant weather features

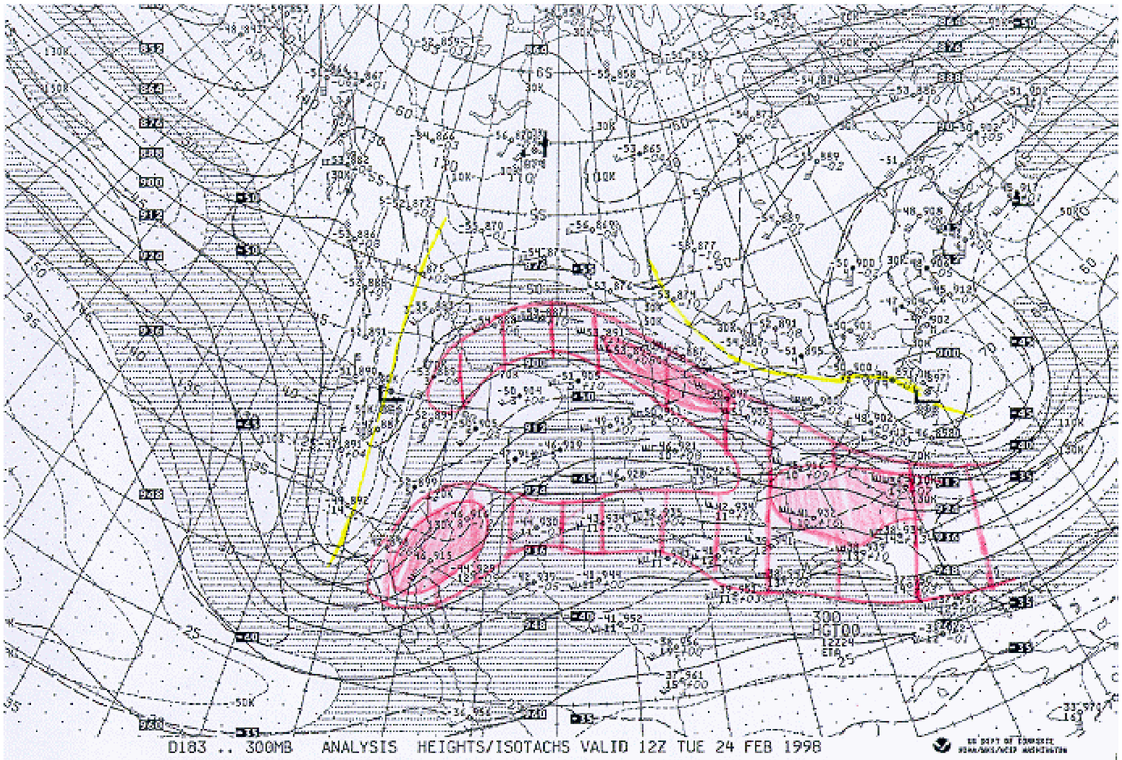
At 1200 UTC, a closed 300 mb low was centered along the Virginia coast. A rather sharp trough axis extended northwestward from the low, across northern Ohio to Minnesota. Jet stream winds in excess of 90 knots were present to the south of the trough. The left-exit region of a jet streak reached the Chicago area by this time, possibly providing some extra lift there. At 500 mb, the low/trough setup was similar, but shifted slightly to the north. The trough axis ran across Lake Erie and central Michigan. Warm and cold advection were quite evident on the north and south side of the trough, respectively. Saturated air

surrounded the closed low and reached as far west as the Ohio-Pennsylvania border. At 700 mb, the pattern was again shifted further to the north, and the low was much stronger. Similar temperature advection and moisture patterns were in place, but the cold advection was much more extensive. Moisture covered most of Ohio and northern Michigan, but a swath of very dry air ran between Chicago and Detroit. The dry air was also present over these locations at 850 mb, while moist conditions prevailed across the rest of the forecast area. The low was even stronger and slightly further offshore at 850 mb. The trough axis was still draped across the east ends of Lakes Erie and Huron, connecting to a closed low near Hudson's Bay. Cold advection was only found across the South, and weak warm advection was noticeable around Lake Erie.

The 1200 UTC surface map (Fig. 2) featured a strong, 986 mb occluding low off the coast of New Jersey. A strong pressure gradient and northwesterly winds dominated the mid-Atlantic states. These winds were weaker in the more slack pressure gradient over Ohio. Widespread precipitation occurred around a western side of the low, with rain falling within 200 miles of the coast, some freezing rain and ice pellets in northern Pennsylvania, and snow further to the north and west. Eastern Ohio was located just to the west of that precipitation, while western Ohio was beginning to feel the effects of an approaching trough/weak front. A swath of rain, snow, and occasional ice pellets preceded the front and both moved eastward across western Ohio between 1200 and 1800 UTC (Fig. 3). The Twin Otter sampled this feature and the overcast skies that surrounded it. The precipitation weakened and became less organized after 1600 UTC.

Satellite data from 1415 UTC (Fig. 4) clearly show the two storms systems. Deep, cold cloud dominated much of the Northeast. The back edge of these clouds clipped Ohio, but was just to the east of Cleveland, which was in broken clouds between the systems. To the west, a swath of clouds dipped from Michigan into western Ohio. CTTs decreased quickly from near -10C at the leading edge to as cold as -25C within the heart of the precipitation. As the clouds marched into central Ohio, they became less organized and their tops warmed in many places. This matched the breakup of the precipitation, as seen in the radar mosaic plots.

No sounding taken the across the region was representative of the cloud and precipitation swath (Fig. 5). The Pittsburgh and Buffalo soundings both sampled the deep clouds on the back side of the East Coast storm. Detroit was in the clear slot between systems, and Wilmington was at or just ahead of the warm leading-edge clouds (see the 1215 UTC infrared satellite image - Fig. 4). The Wilmington sounding did go through some thin, patchy, warm cloud decks, and featured a cold advection wind profile below about 800 mb (near cloud top, CTT = -5C). Quite a few icing PIREPs were made within the western swath of cloud (Fig. 6). Most aircraft reported moderate severity rime and mixed icing at altitudes between 7000’ and 11,000’. Once severe rime PIREP was made early in the day by an ATR at 9000’ within an area of warm clouds on the trailing edge of the system. These areas shrunk considerably as the clouds moved through western Ohio.



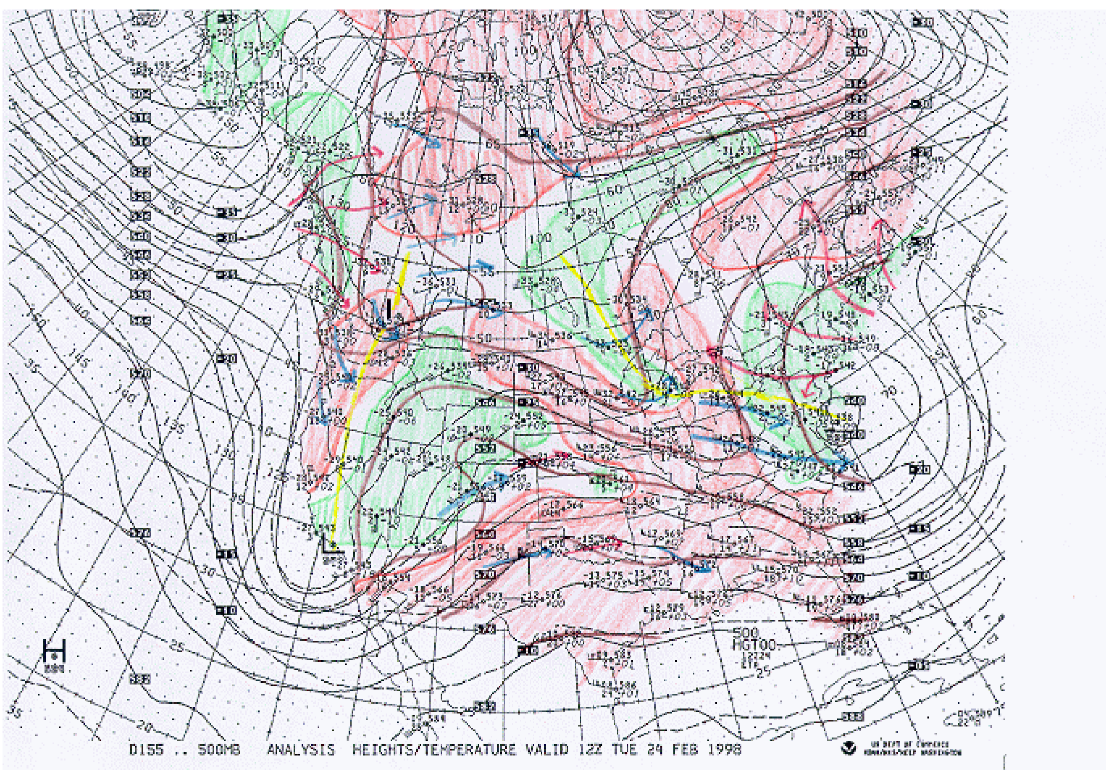
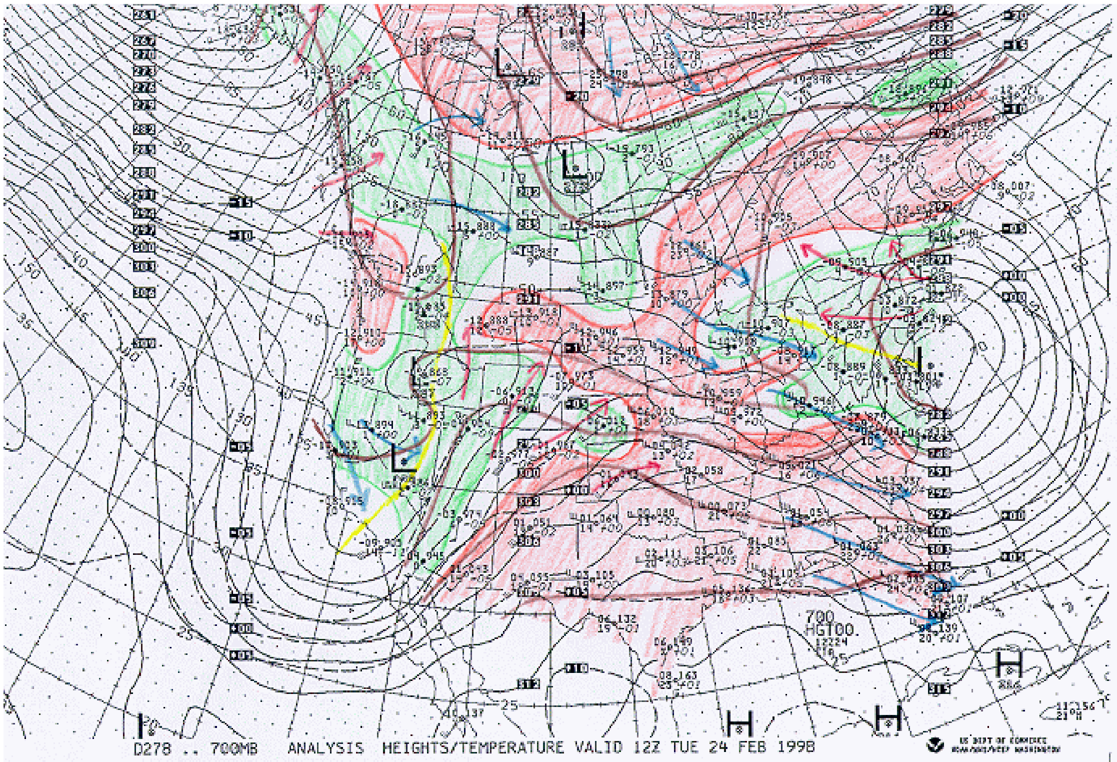


Figure 1 – Upper-air charts for 980224, 1200 UTC at a) 300 and b) 500 mb.



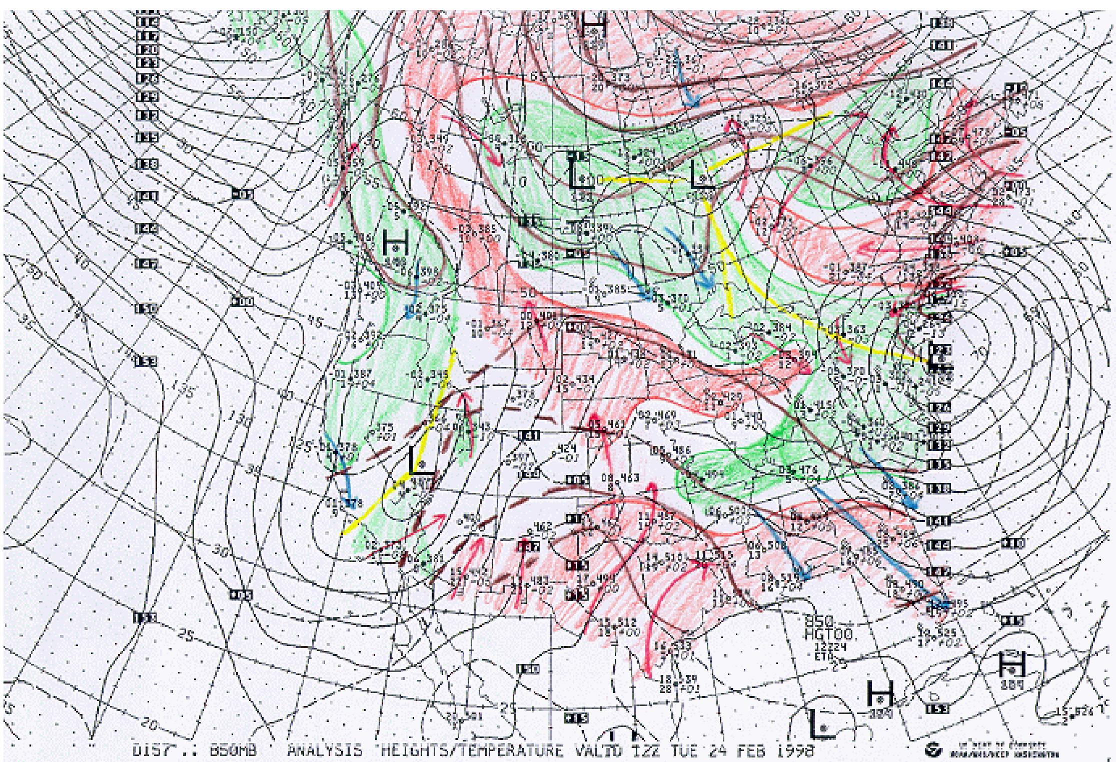


Figure 1 – Upper-air charts for 980224, 1200 UTC at c) 700 and d) 850 mb.

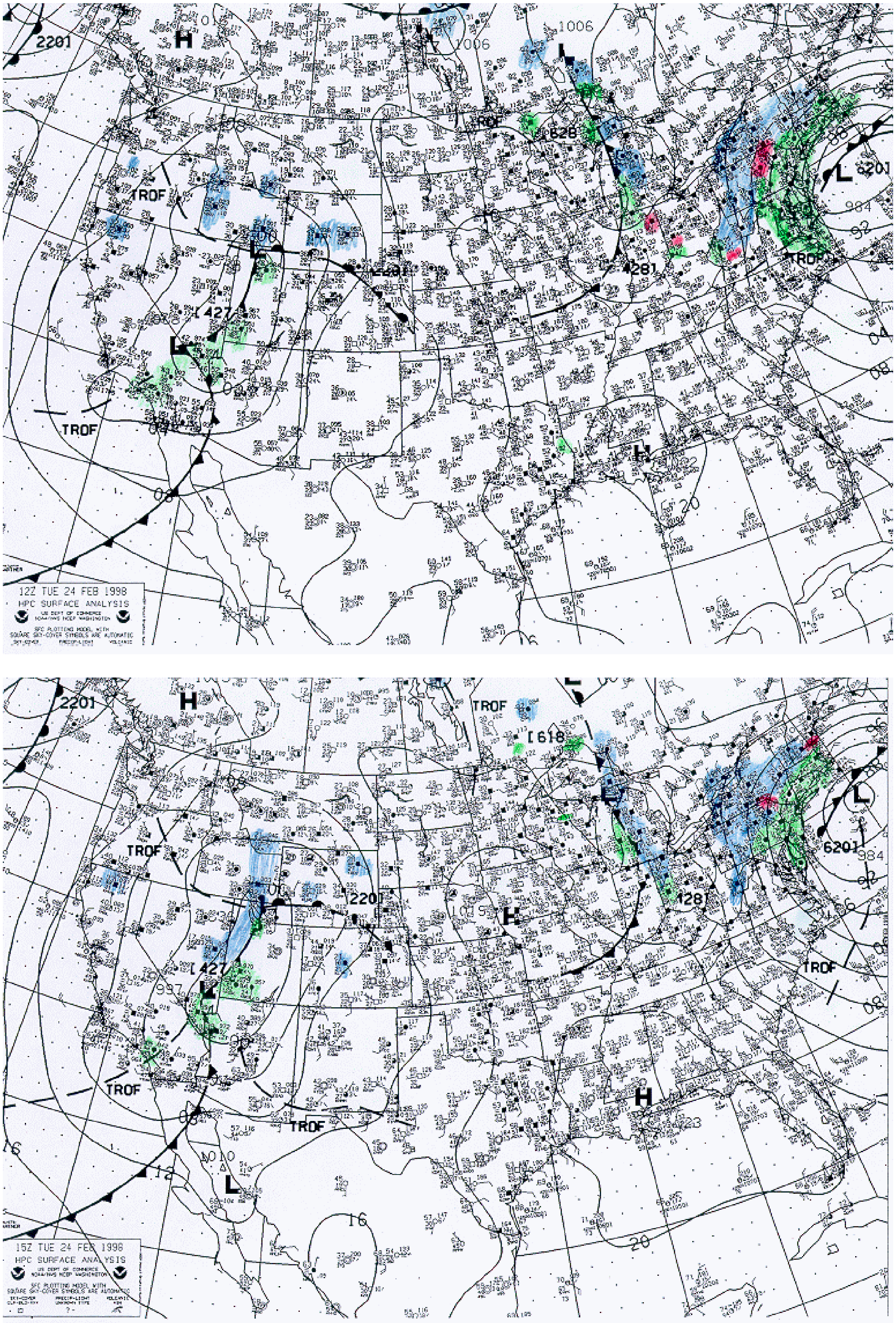
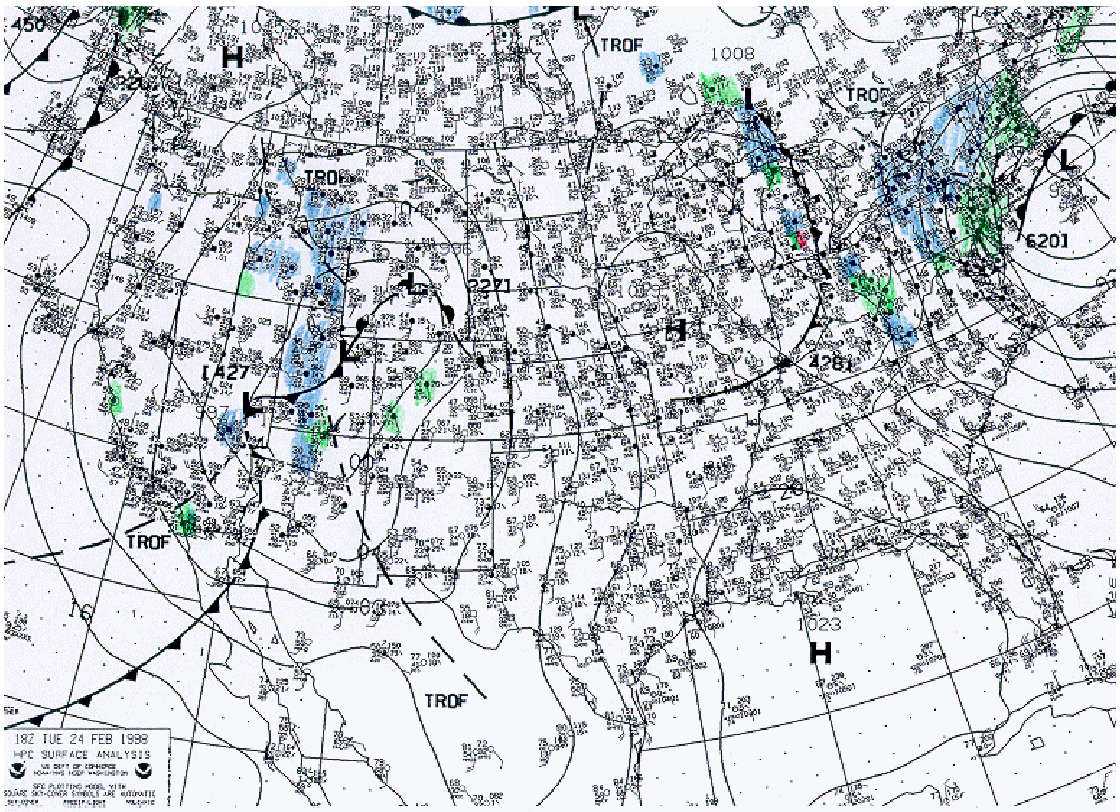


Figure 2 – Surface charts for 980224, a) 1200 and b) 1500 UTC.



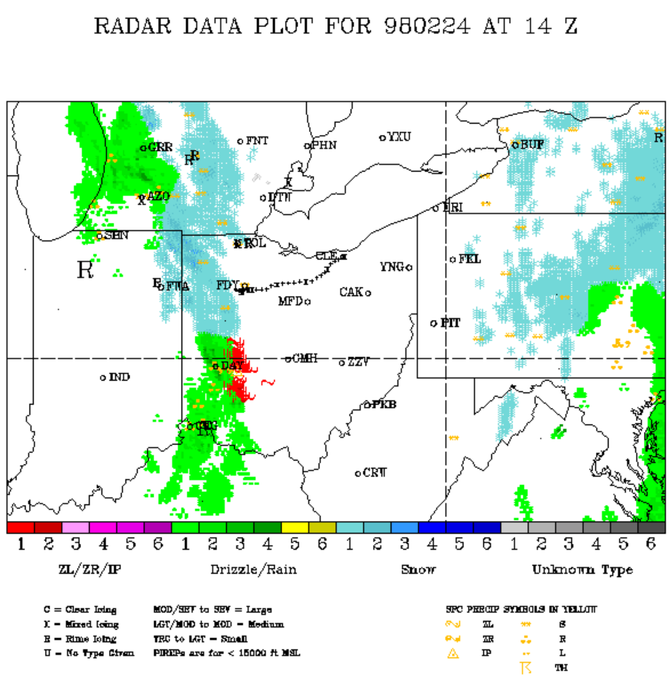
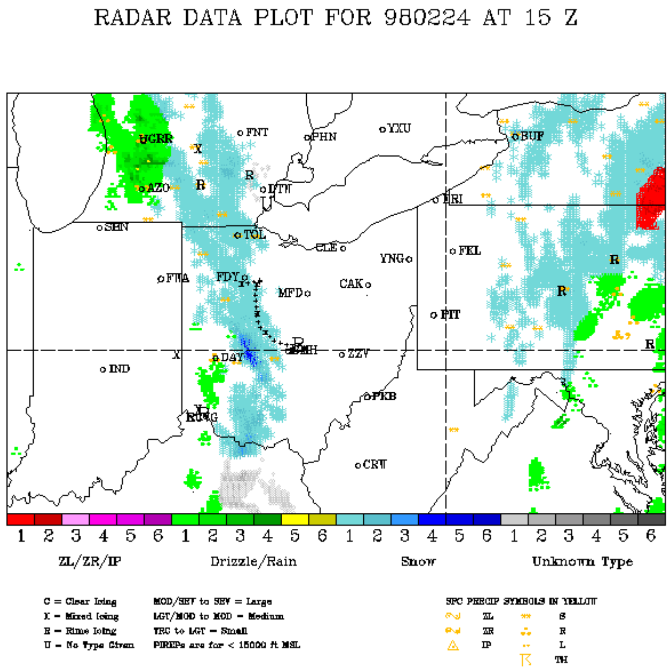


Figure 2 – Surface chart for 980224, c) 1800 UTC.
Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980224, a) 1400 UTC.



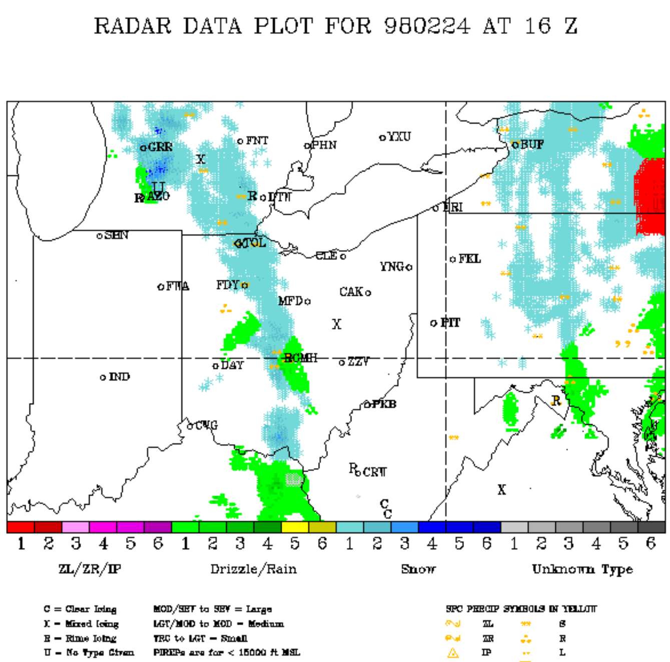
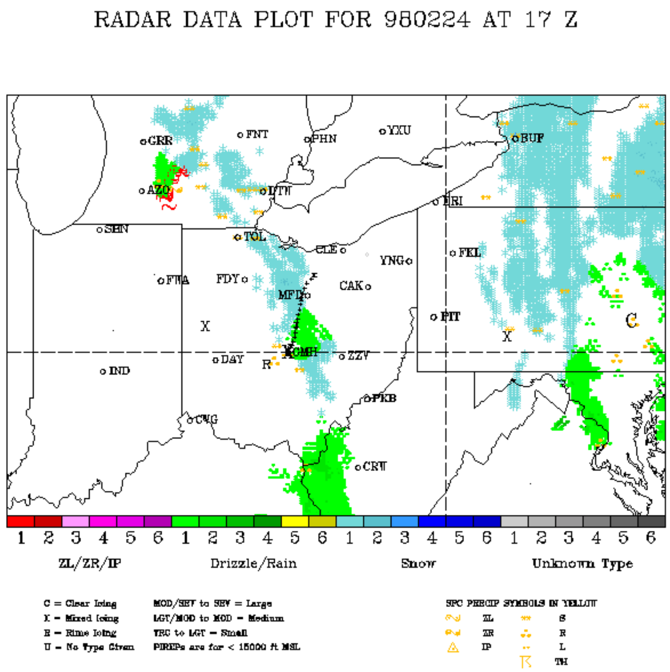


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980224, b) 1500 and c) 1600 UTC.



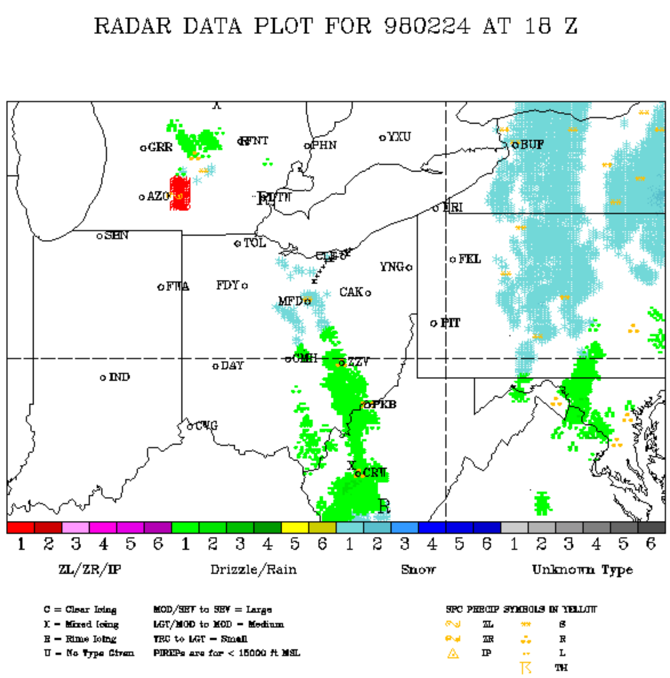


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980224, d) 1700 and e) 1800 UTC.

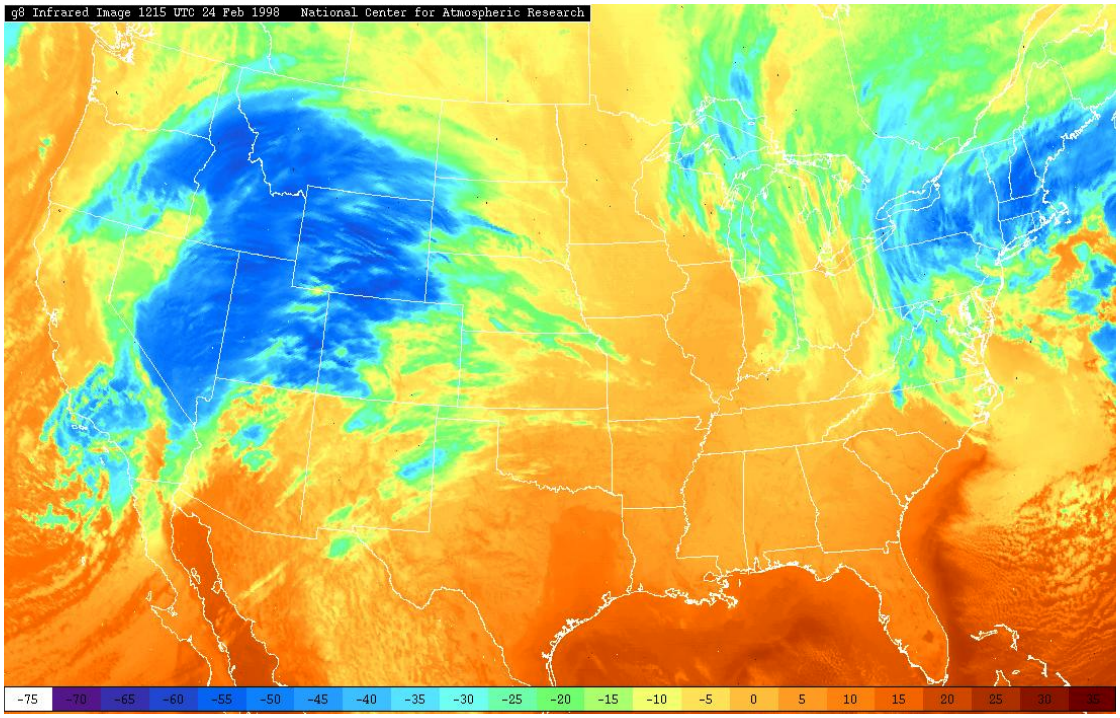
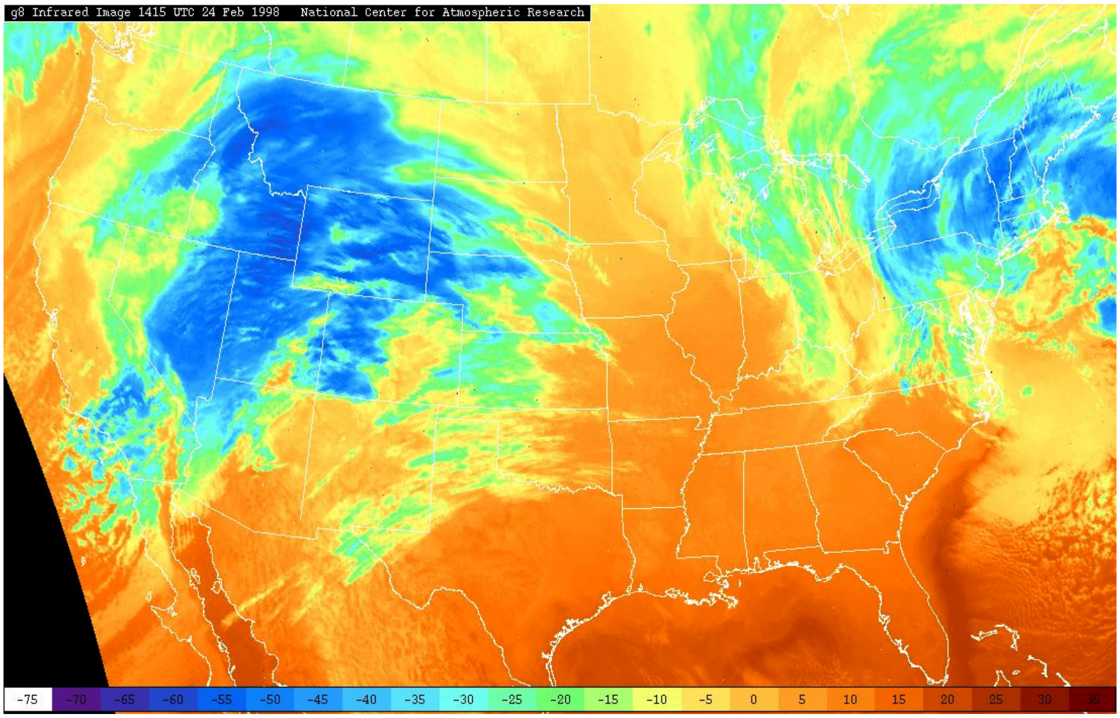


Figure 4 – GOES-8 a) infrared satellite image for 980224, 1215 UTC.



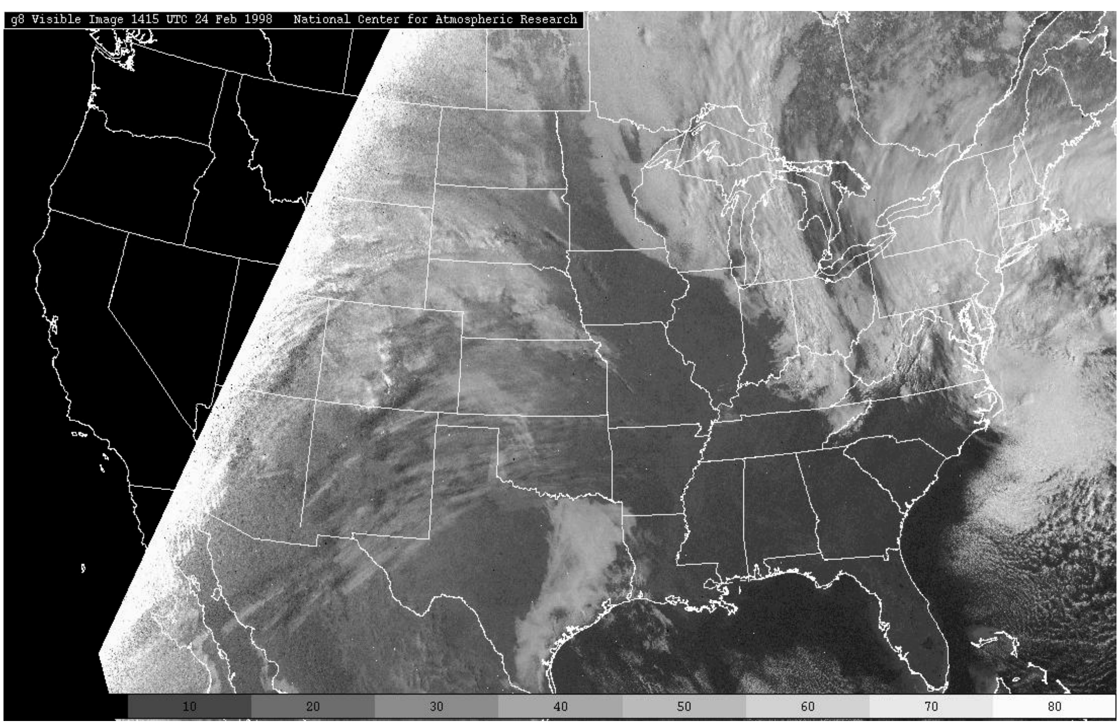
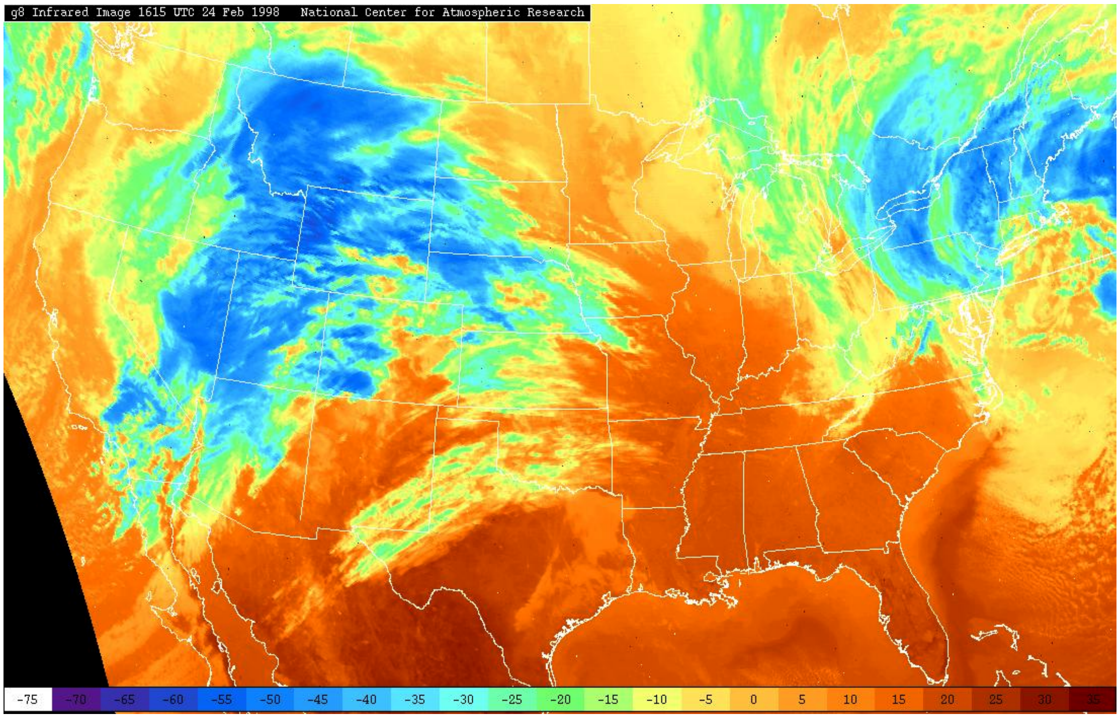


Figure 4 – GOES-8 b) infrared and c) visible satellite images for 980224, 1415 UTC.



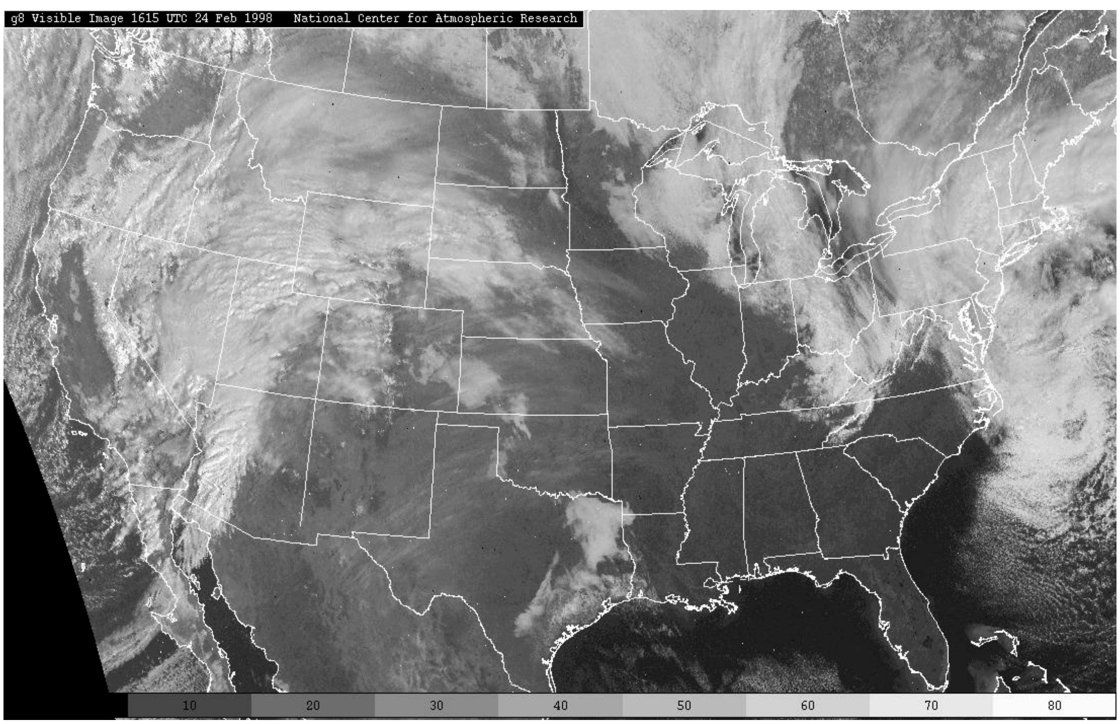
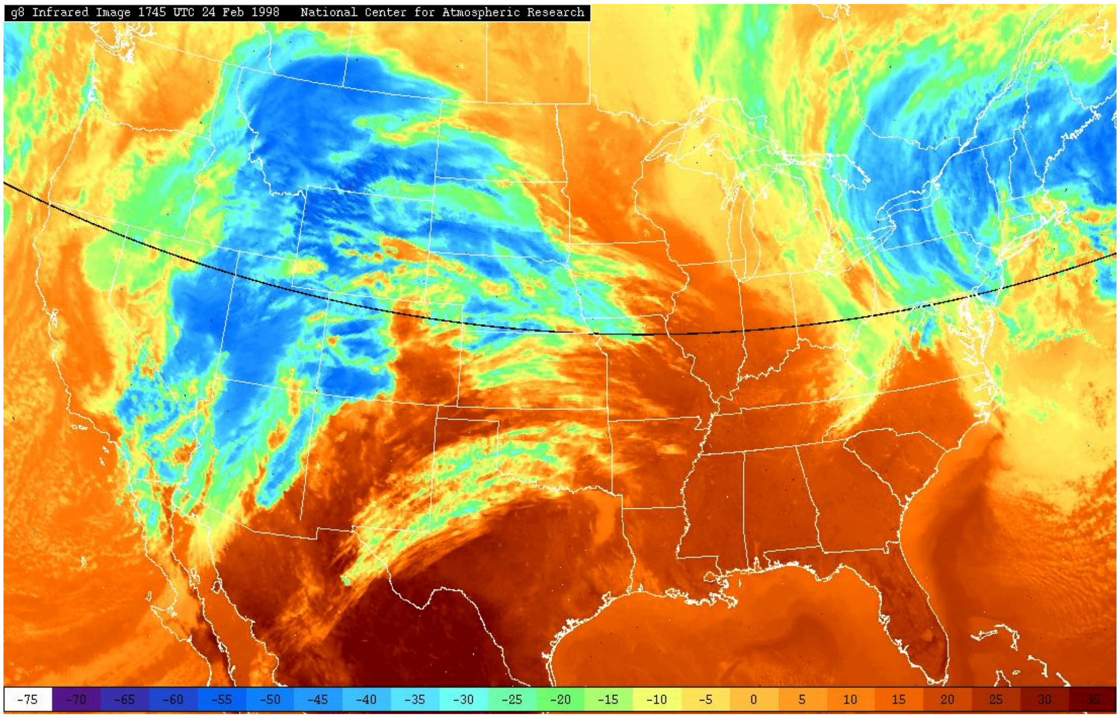


Figure 4 – GOES-8 d) infrared and e) visible satellite images for 980224, 1615 UTC.



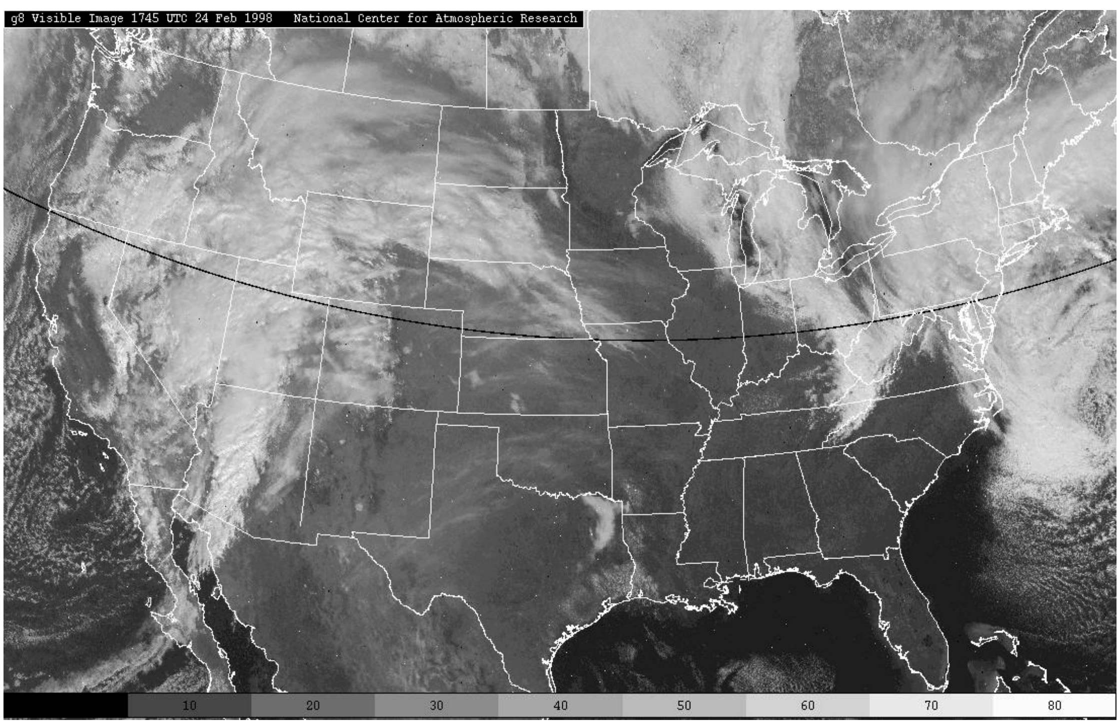
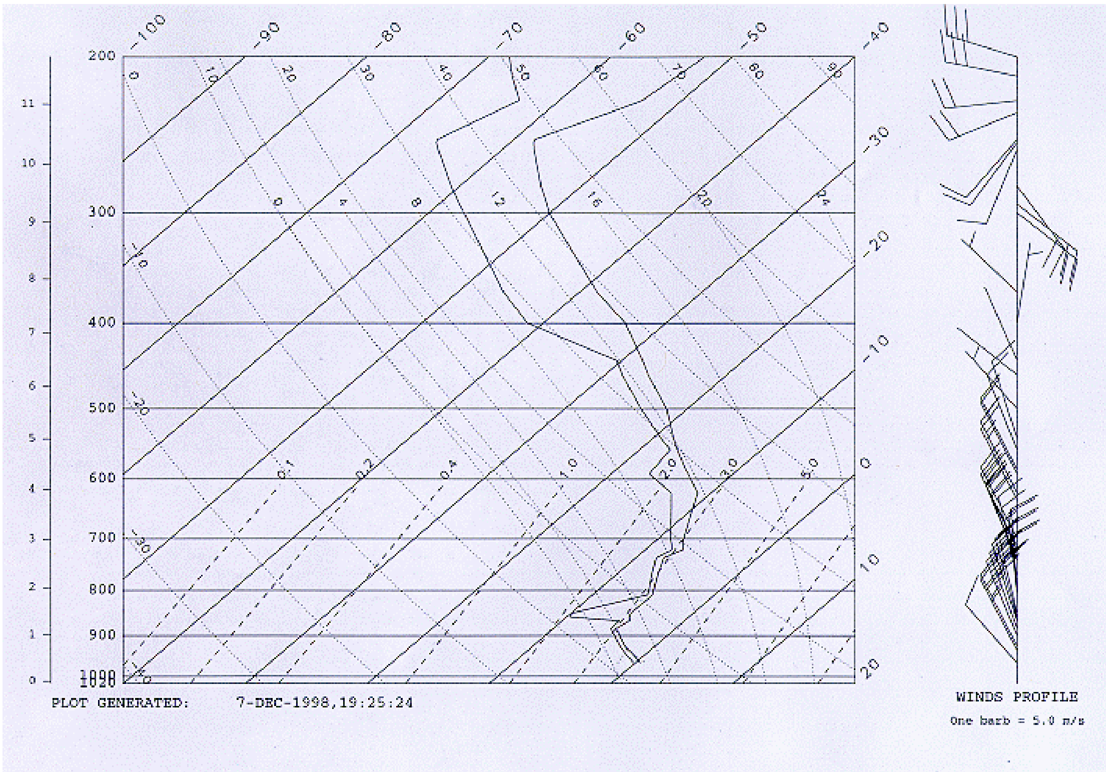


Figure 4 – GOES-8 f) infrared and g) visible satellite images for 980224, 1745 UTC.



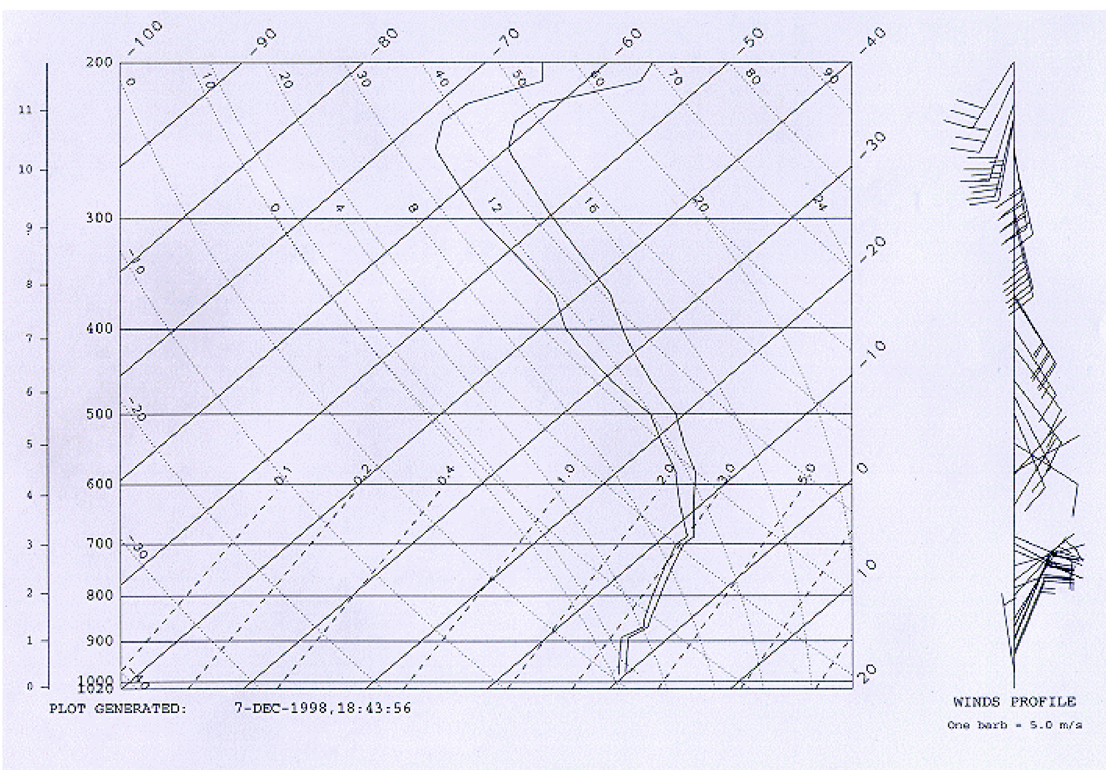
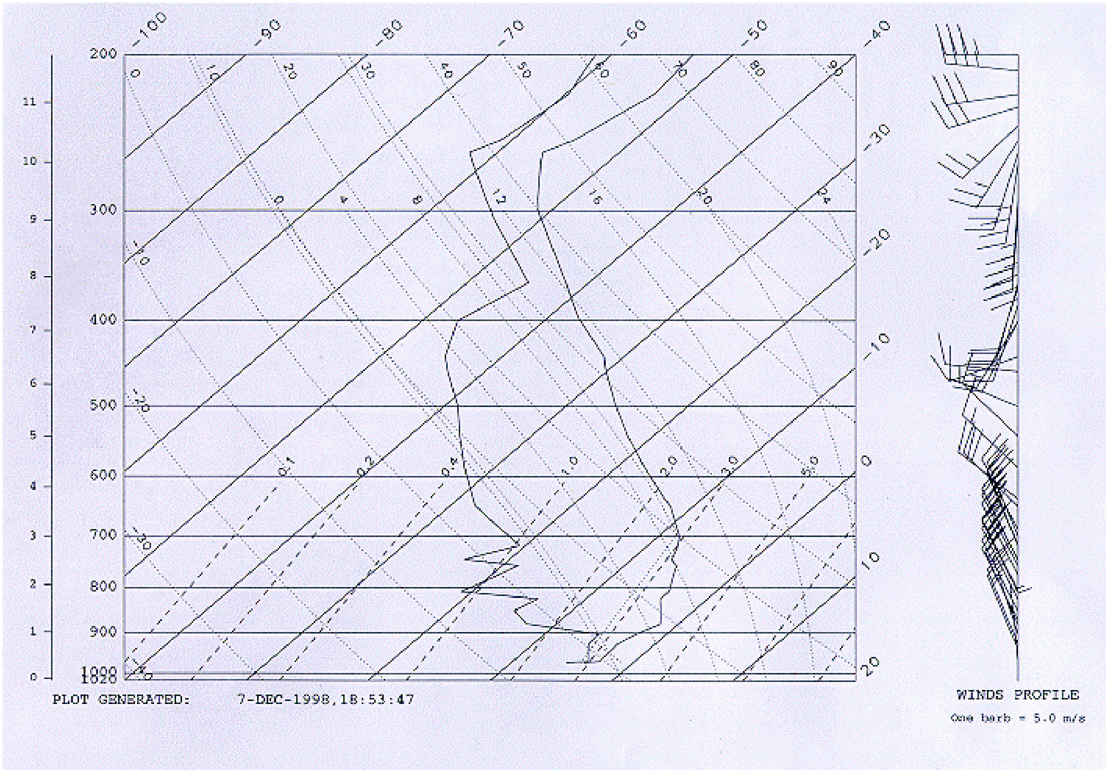


Figure 5 – Balloon-borne soundings from a) Pittsburgh and b) Buffalo at 980224, 1200 UTC.



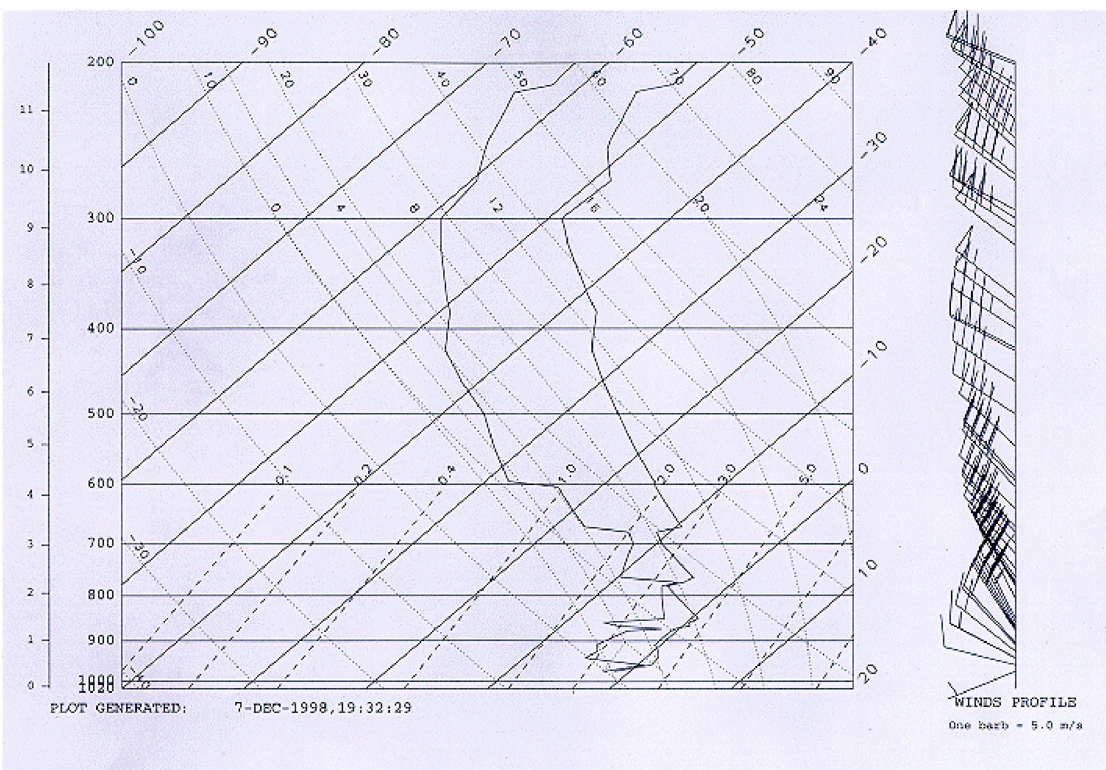
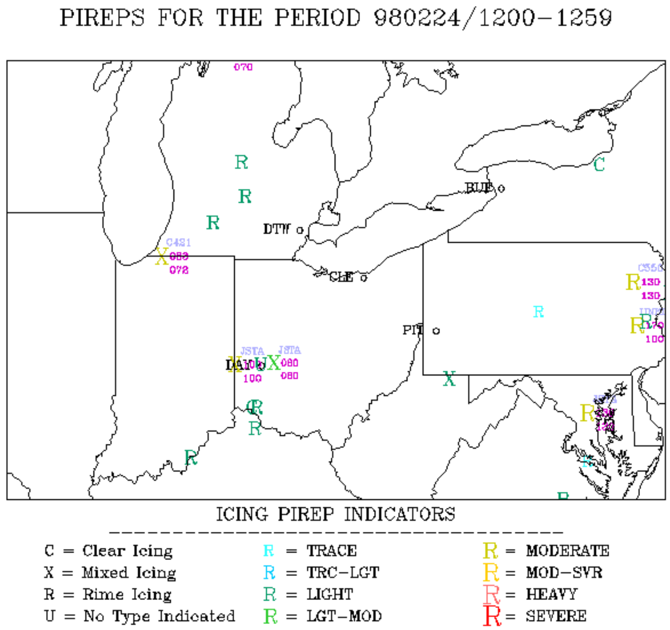


Figure 5 – Balloon-borne soundings from c) Detroit and d) Wilmington at 980224, 1200 UTC.



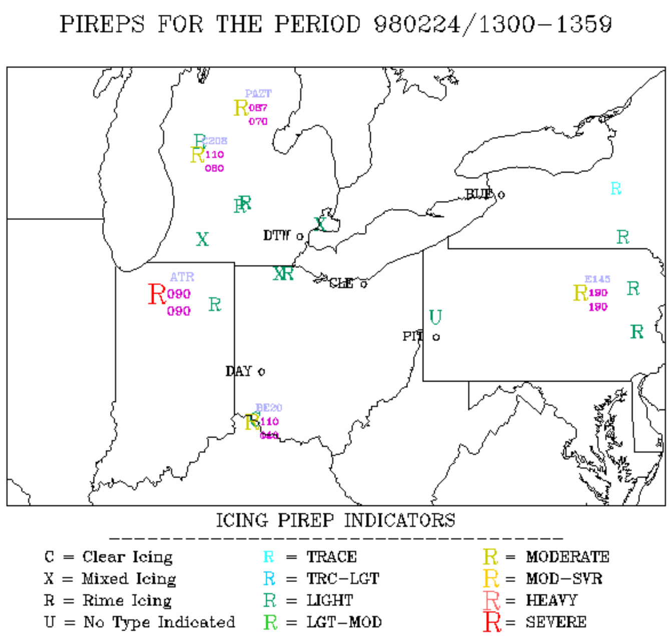


Figure 6 – Pilot reports of icing for 980224, a) 1200-1259 and b) 1300-1359 UTC.

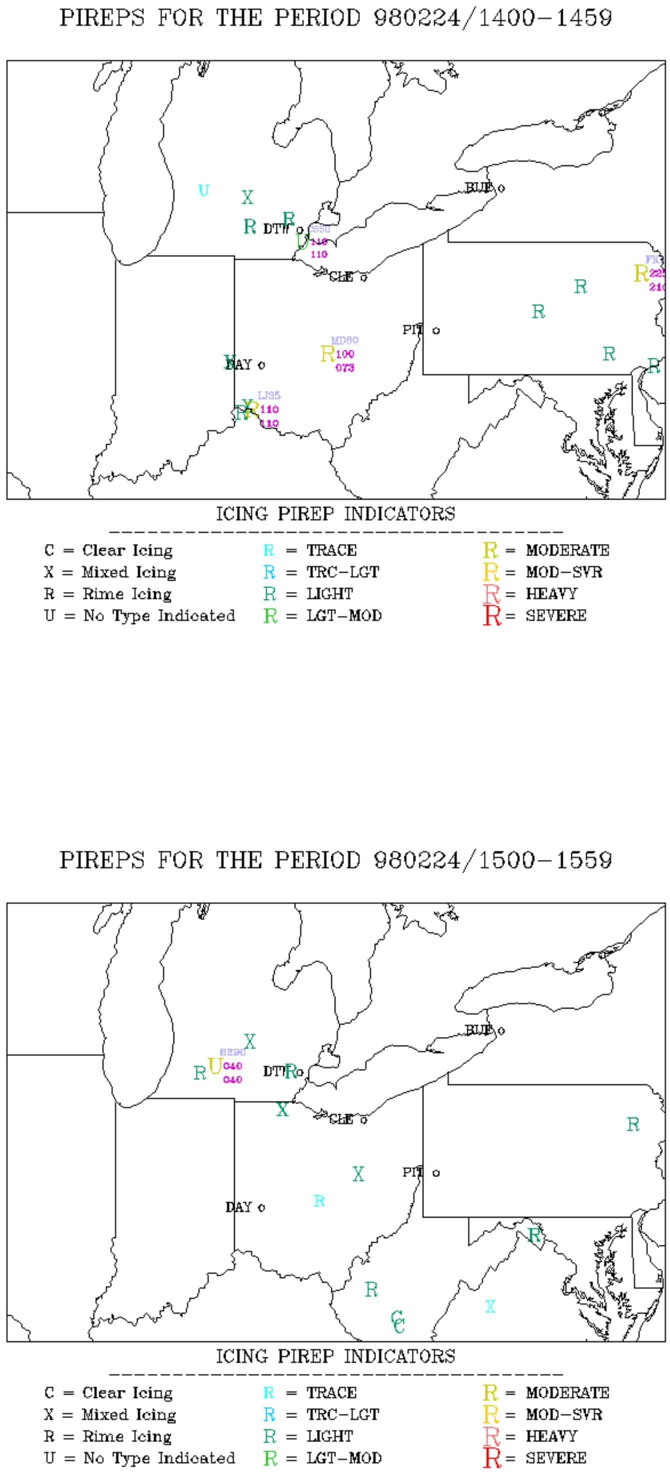
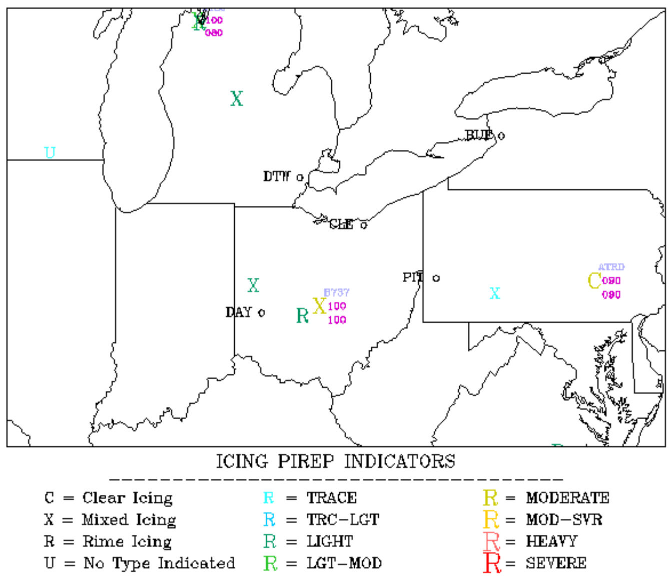


Figure 6 – Pilot reports of icing for 980224, c) 1400-1459 and d) 1500-1559 UTC.

PIREPS FOR THE PERIOD 980224/1600-1659



PIREPS FOR THE PERIOD 980224/1700-1759

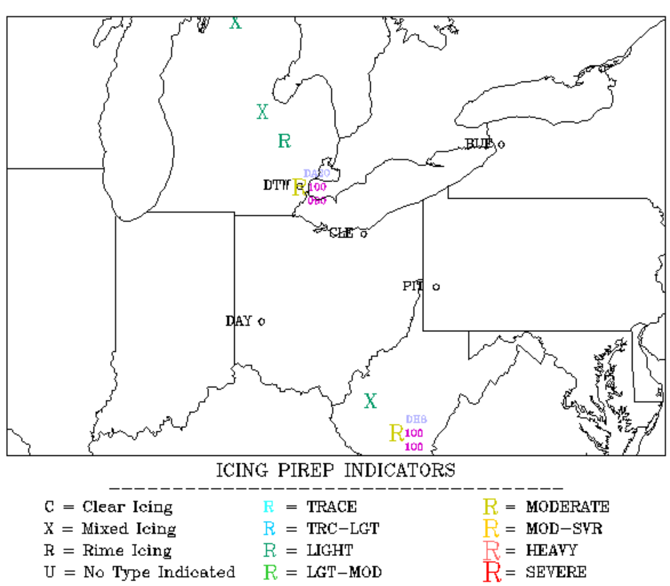


Figure 6 – Pilot reports of icing for 980224, e) 1600-1659 and f) 1700-1759 UTC.

February 27, 1998

Flight #1—Over Lake Erie and Toledo. OH, from 1333 to 1523 UTC.

Flight #2—Over Jackson, Flint, and Saginaw, MI, from 1630 to 1838 UTC.

Flight #3—Over Saginaw, MI, Selfridge AFB, and Lake Erie from 1930 to 2058 UTC.

Brief overview

Three flights were made within and along the southern side of a band of precipitation that moved northward across Lake Erie and the eastern half of Michigan on this day. During the first flight, the band was sampled over Lake Erie and Toledo. Icing conditions were confined to relatively high altitudes, since the freezing level was near 9000'. Some warm drizzle and rain, and a mixture of ice crystals and small droplets were observed below and above the melting level, respectively, on initial climbout from Cleveland. Cloud tops seemed to be near 13000', with CTT of –6C or so along the southern edge of the precipitation near Mansfield at 1400 UTC. Some freezing drizzle (ZL) was found there. Upon flying further north into the band, cloud tops were higher and colder, and cloud was sampled at altitudes as high as 14900'. The clouds contained highly variable conditions, with LWC between 0 and 0.4, temperatures near –8C, and areas of ZL, cloud droplets, ice crystals, and mixtures thereof. Grey probe noise was evident at times, and the probe stopped working at 1419 UTC. The data system was restarted at 1454 UTC, but little/no icing was sampled before landing at Toledo.

During the second flight, the aircraft flew quickly northward to catch up to the precipitation band and cloudiness, reaching it at Saginaw MI. Similar conditions to those seen during the first flight were sampled over and to the north of Saginaw. There were several periods between 1714 and 1735 UTC during which ZL was dominant. Other pockets of ZL were observed through 1800 UTC. LWC was between 0 and 0.2 during most of the ZL encounters, and temperatures were near –8C. LWC was as high as 0.4 during most other times, but reached 1.2 at altitudes near 11000' over Saginaw, just before final descent. Ice crystals were present off and on, including during periods of ZL.

The third flight was essentially a ferry flight home, but small droplets, ice crystals and mixed conditions were observed between 7000' and 9000' between Saginaw and the north shore of Lake Erie.

Relevant weather features

At 1200 UTC, a broad, 300 mb trough covered the western High Plains, while a second, east-west oriented trough reached the Indiana-Michigan border (Fig. 1). A jet maximum ran from Texas up to Kentucky, but did not appear to affect the area of flight on this day. At 500 mb, the High Plains trough became a closed low over Nebraska and the Dakotas, with the east-west trough running from Nebraska to southern Michigan. Cold advection trailed the western end of the trough, but became weak over the forecast area. Moist air covered Michigan, northeastern Ohio, and Pennsylvania, while very dry air had reached Indiana and central Ohio on southwesterly winds. A narrow ridge was pinned over central New

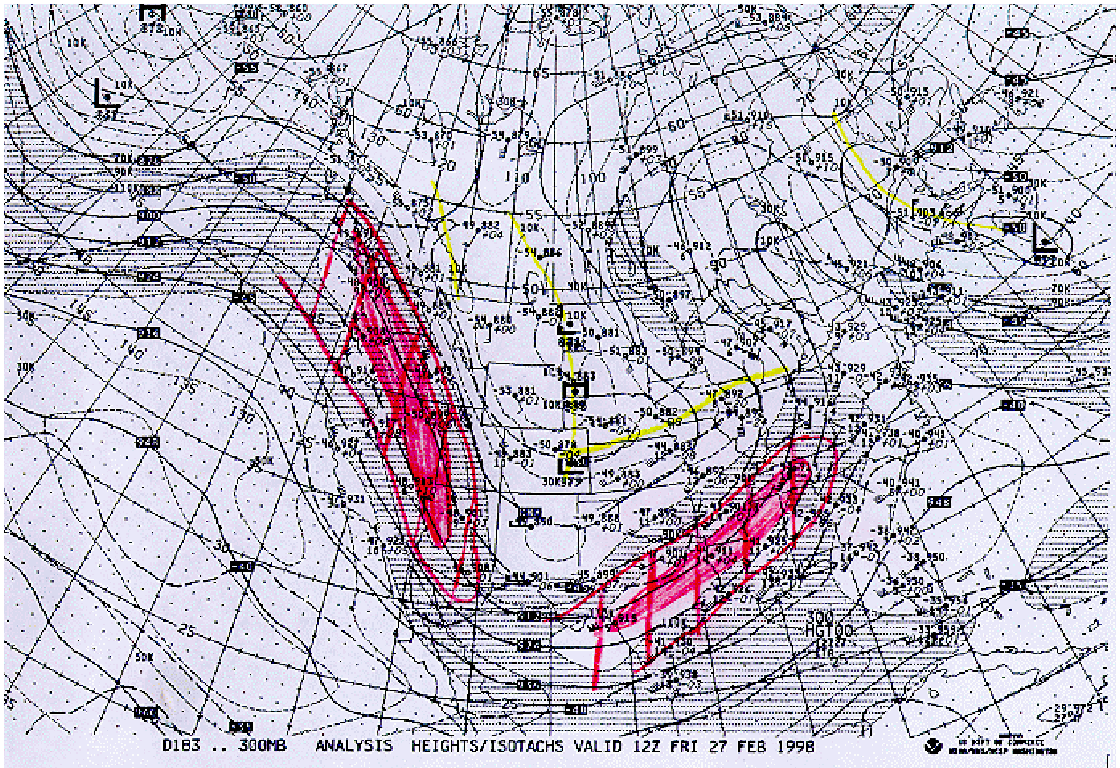
York, between the High Plains low and another closed low off the Maine coast. At 700 mb, the western low became more organized, while the east-west trough continued to stretch across southern Michigan. Strong cold advection trailed the trough, covering much of Indiana and Ohio, and the saturated air shifted to the southwest. Warm advection was present to the north of the trough, and dry air was evident across northern Michigan, northeast Ohio, and much of the East Coast. The fairly strong 850 mb low was centered over northeastern Iowa, with the trough axis still in place over southern Michigan. Warm advection was now fairly strong to the north of the trough, while cold advection was still prevalent to its south. Moisture at this level was in roughly the same location as it was at 700 mb.

By 0000 UTC (Fig. 2), dry air took over the forecast area at 500 mb, as the closed low slid northeastward into Iowa, and the trough moved slightly northward into central Michigan. Cold and warm advection continued to trail and precede the trough, respectively. At 700 mb, the low strengthened and became more closed off over southern Minnesota, while the trough moved northward. Strong cold advection covered areas to the south of the trough, and the swath of moisture curled across the northern tip of Michigan, then into eastern Ohio and western Pennsylvania. The low and trough made similar moves at 850 mb, but the cold advection and warm advection on either side of the front weakened. Moisture covered Michigan, but dry air punched into Ohio from the southwest.

Surface charts for the period (Fig. 3) nicely reflected the progression of this occluding system. A strong (989 mb) low that was centered over northern Illinois tracked to the northwest with time, as an occluded surface front moved northeastward across Indiana, Ohio, and Michigan. A band of rain that was oriented with and located ahead of the front also swept northeastward with time. This rain was quite evident in the radar mosaic plots (Fig. 4), and extended into western Pennsylvania. Flights on this day were primarily made within and on the southern fringes of this precipitation.

Satellite data (Fig. 5) showed the fairly well organized clouds ahead of the surface front. Cloud top temperatures quickly decreased from near -10C at the southern edge of the clouds to colder than -40C in the precipitation areas to the north. Dry air moving in from the southwest cleared out most of the clouds over Indiana and western Ohio by 1545 UTC. The dry air pushed into Michigan as the front and upper trough moved northward.

Sounding data from 1200 UTC (Fig. 6) showed a deep, warm cloud layer over Wilmington, while Alpena had very dry air at low-levels and deep, cold cloud above 500 mb. Unfortunately, the Detroit 1200 UTC sounding, which would have been made into the heart of the moisture, was not available. By 0000 UTC, conditions had completely dried out at Wilmington, while the moisture profile at Alpena reversed itself, with only shallow, warm clouds in place behind the upper trough. Detroit was within the dry slot by 0000 UTC. A fair number of moderate severity PIREPs were made at altitudes above 10,000 feet within and to the south of the precipitation (Fig. 7). Some additional PIREPs were made near the low-pressure center and within the warm clouds to its south.



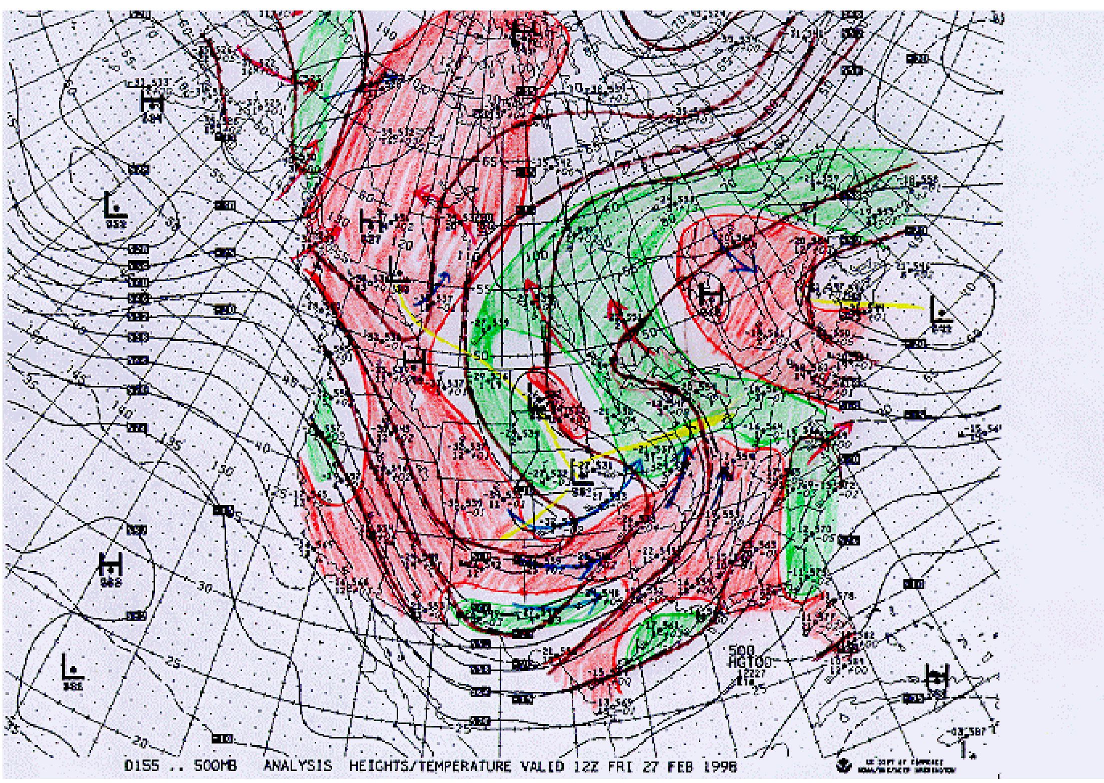
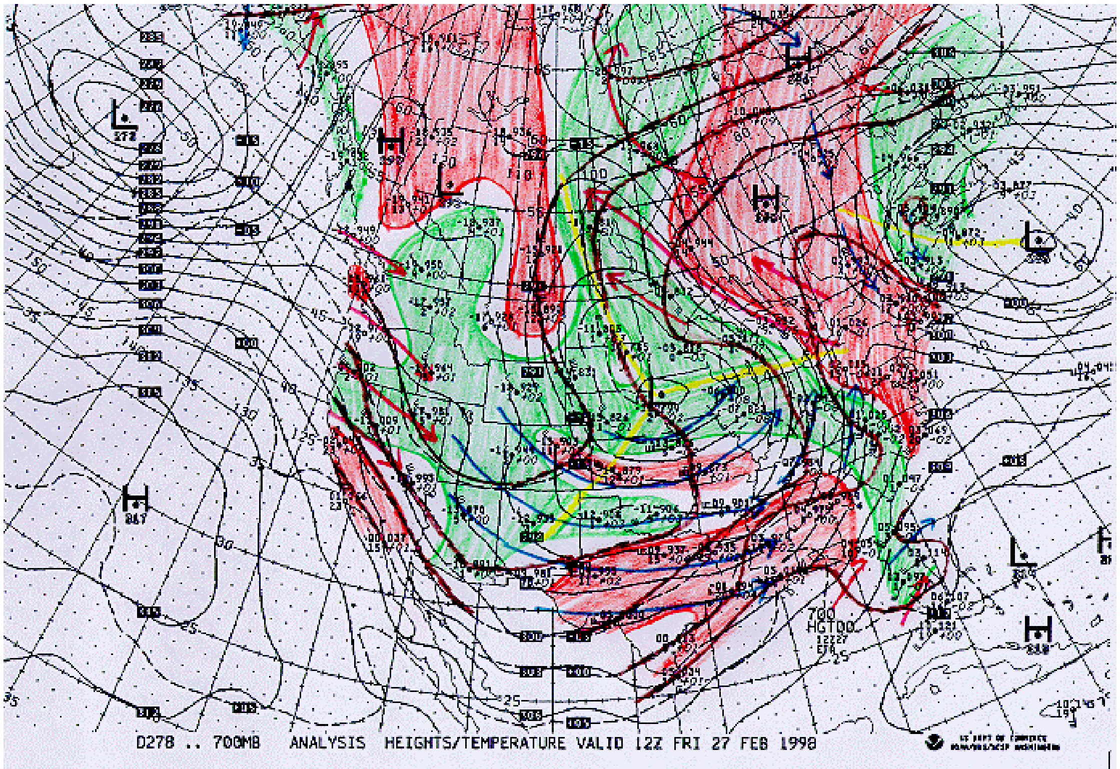


Figure 1 – Upper-air charts for 980227, 1200 UTC at a) 300 and b) 500 mb.



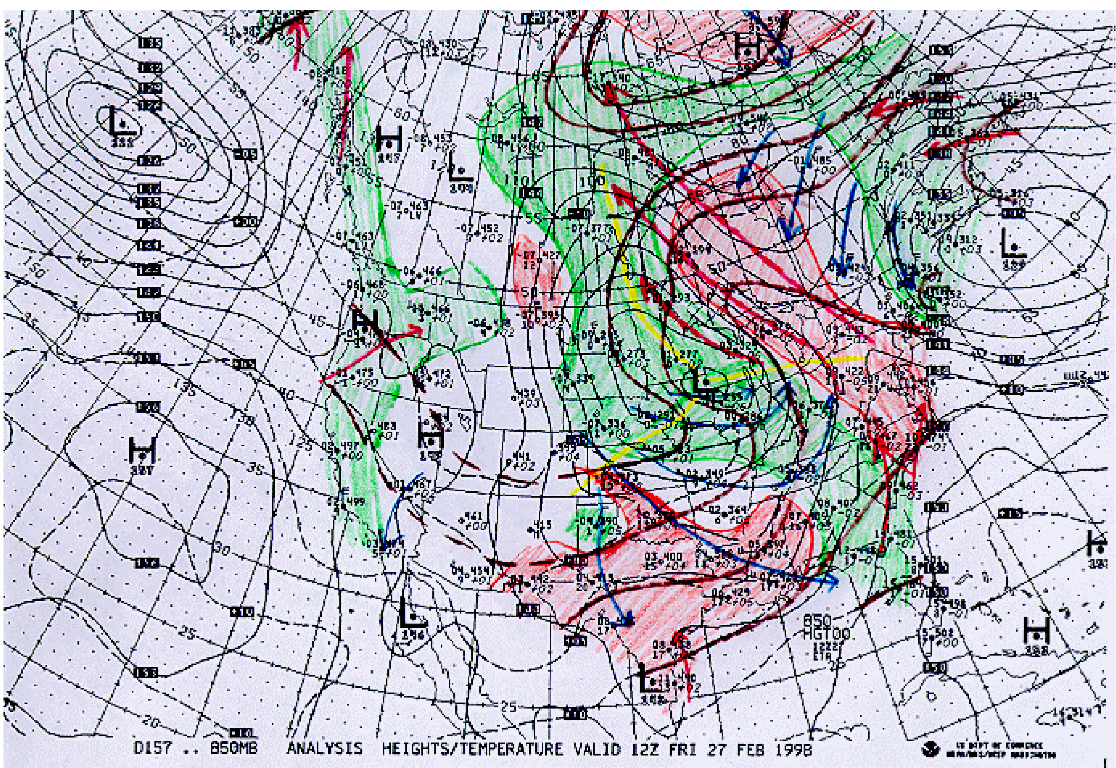
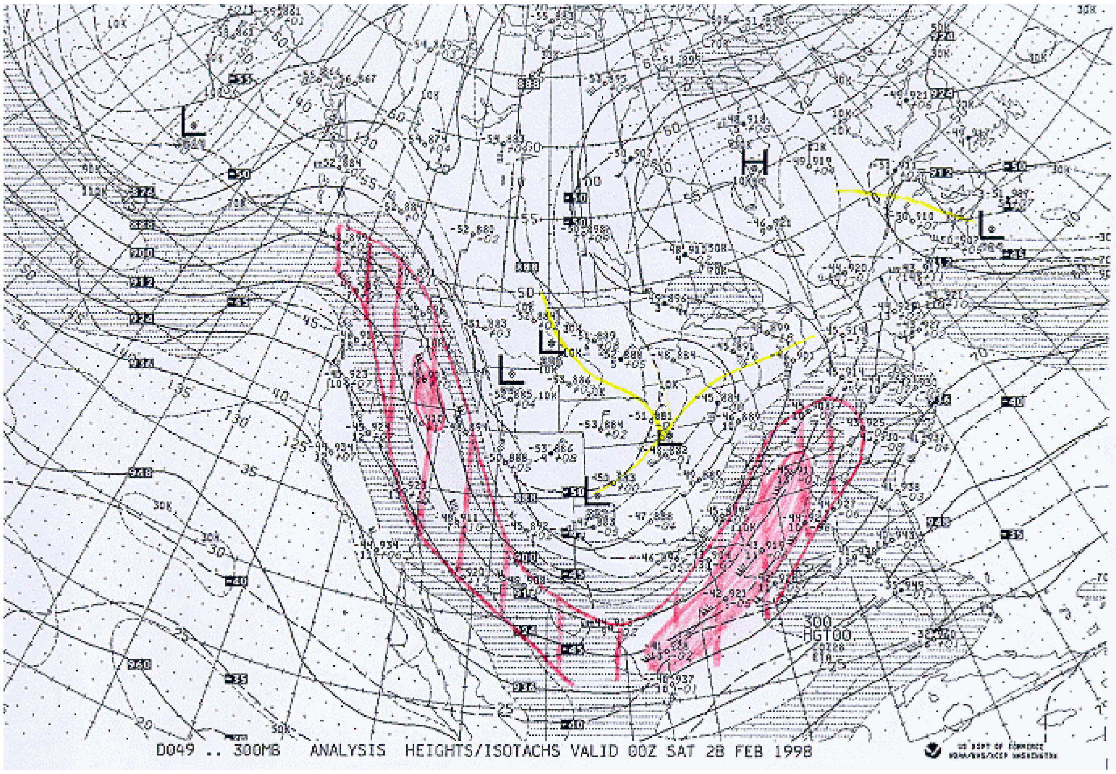


Figure 1 – Upper-air charts for 980227, 1200 UTC at c) 700 and d) 850 mb.



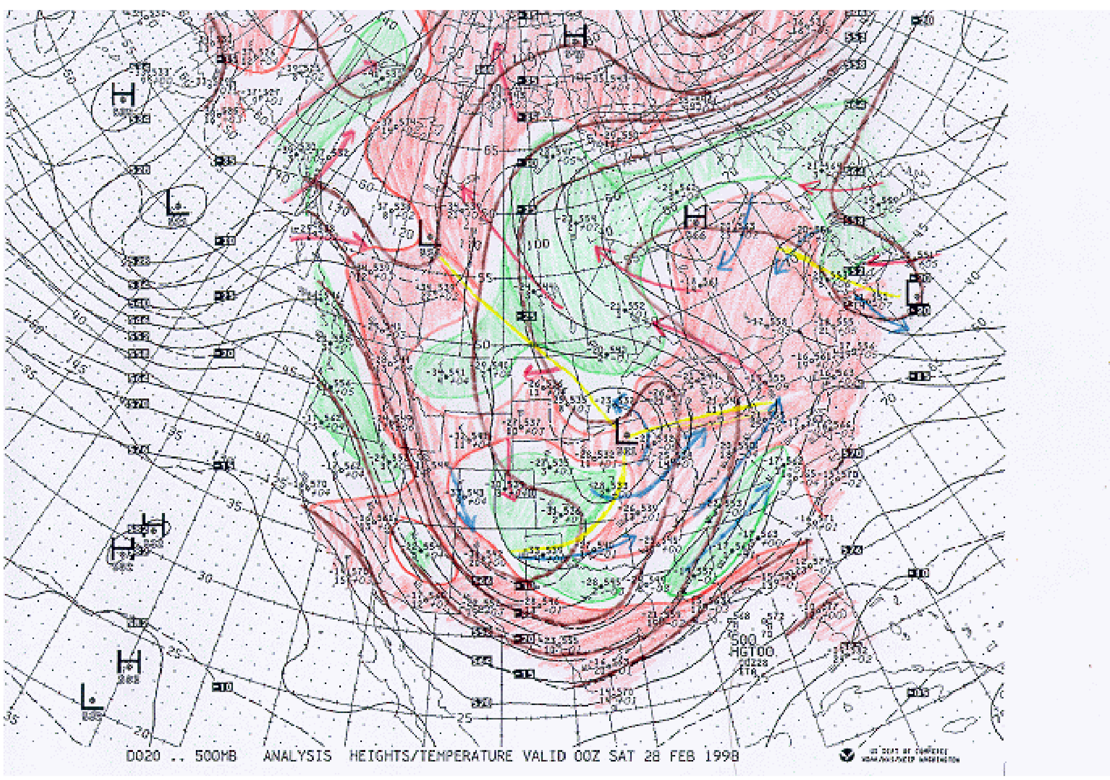
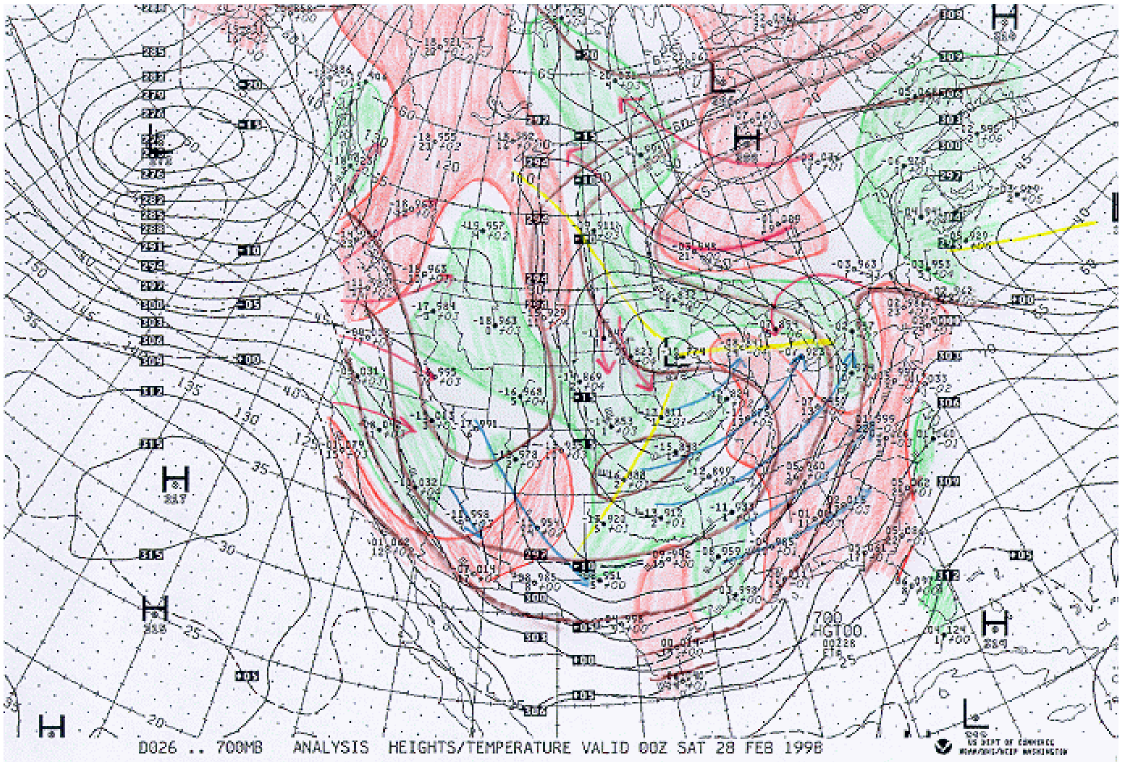


Figure 2 – Upper-air charts for 980228, 0000 UTC at a) 300 and b) 500 mb.



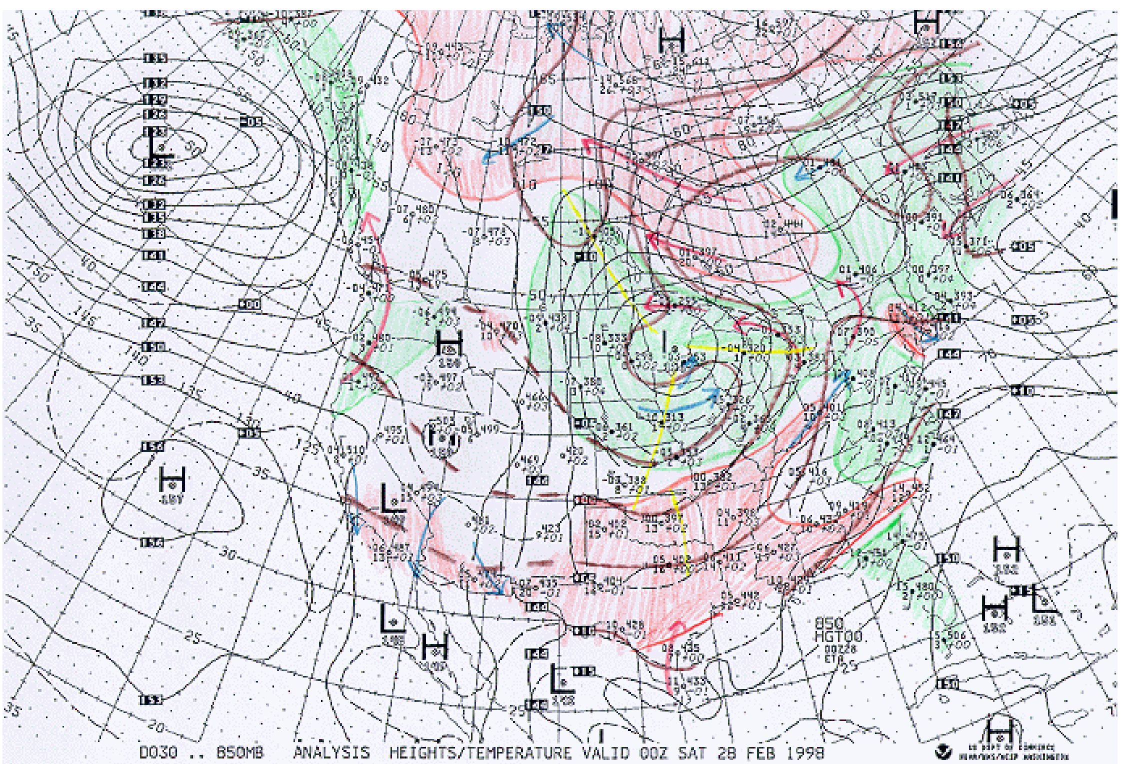
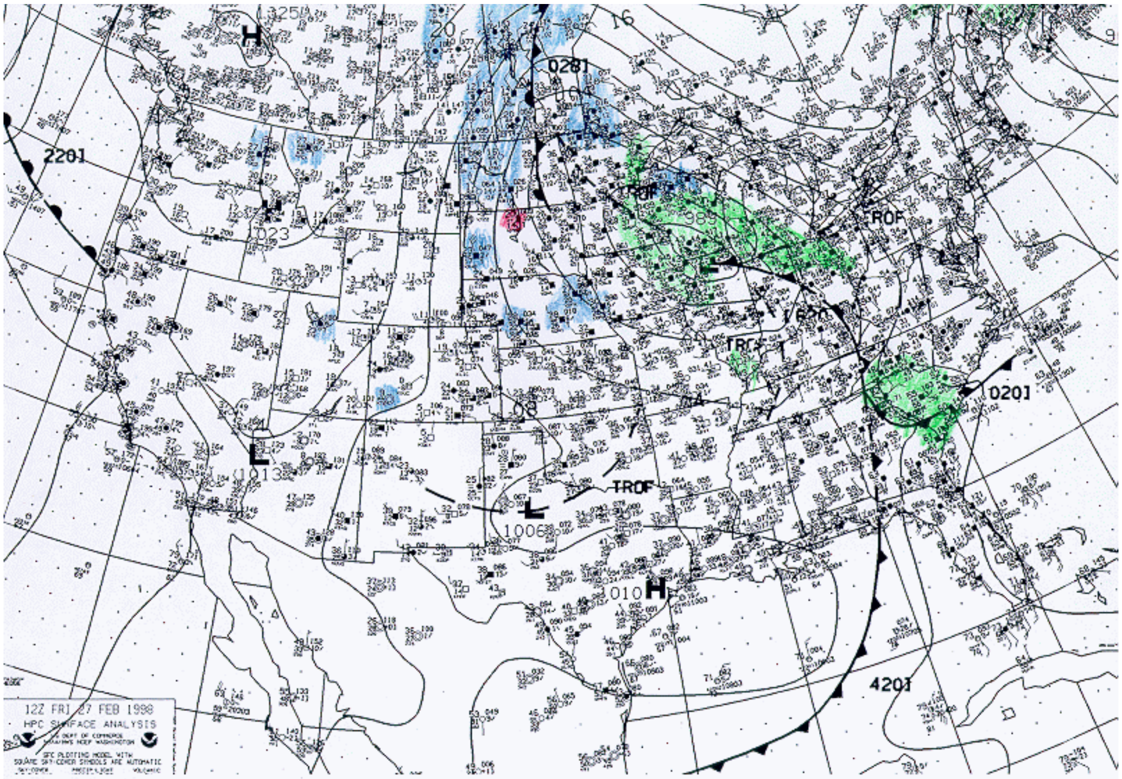


Figure 2 – Upper-air charts for 980228, 0000 UTC at c) 700 and d) 850 mb.



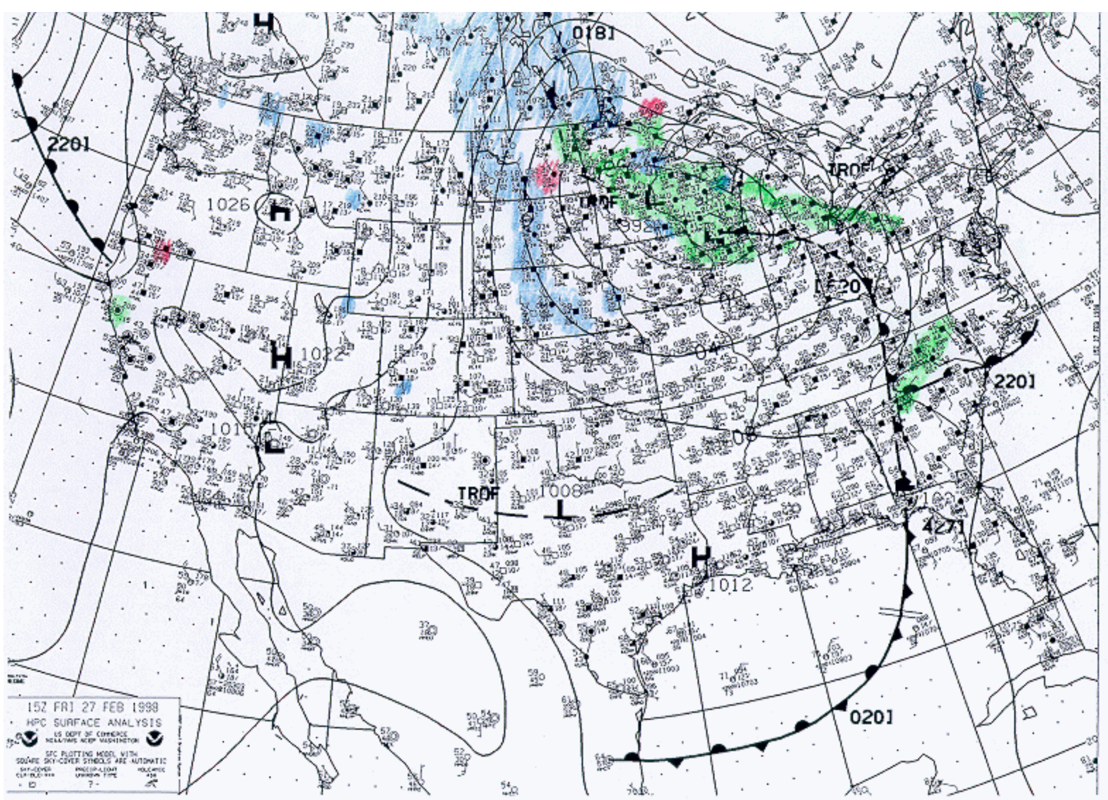
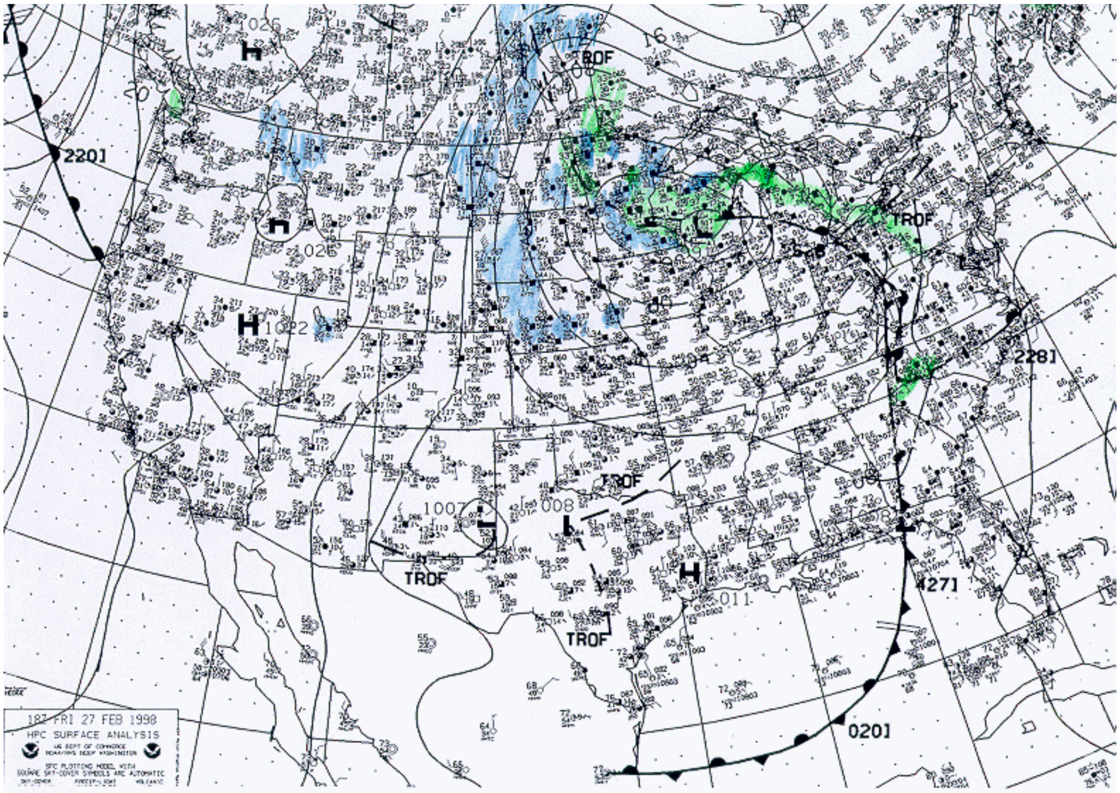


Figure 3 – Surface charts for 980227, a) 1200 and b) 1500 UTC.



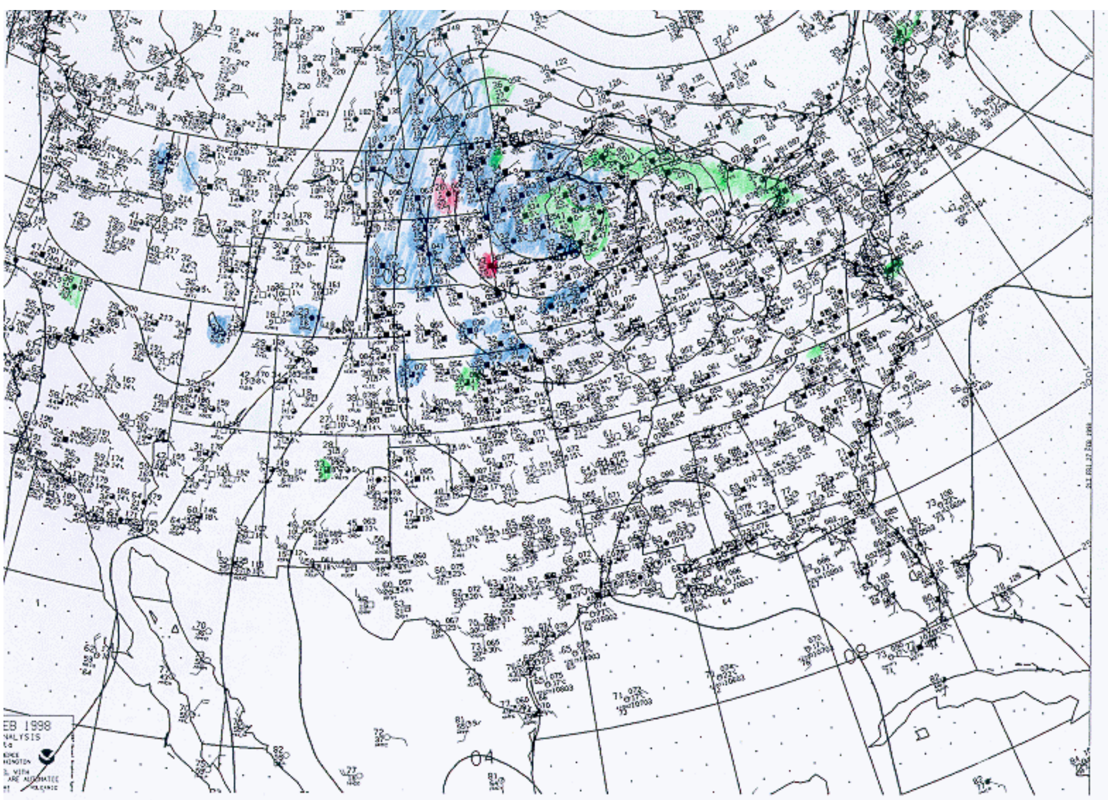
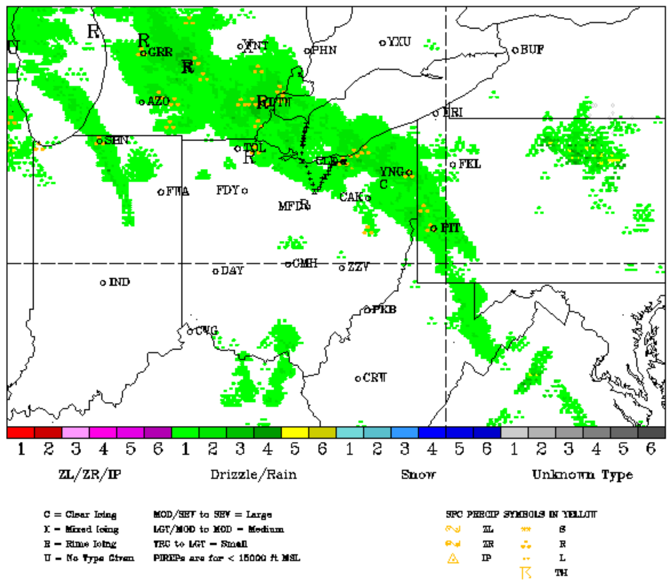


Figure 3 – Surface charts for 980227, c) 1800 and d) 2100 UTC.

RADAR DATA PLOT FOR 980227 AT 14 Z



RADAR DATA PLOT FOR 980227 AT 15 Z

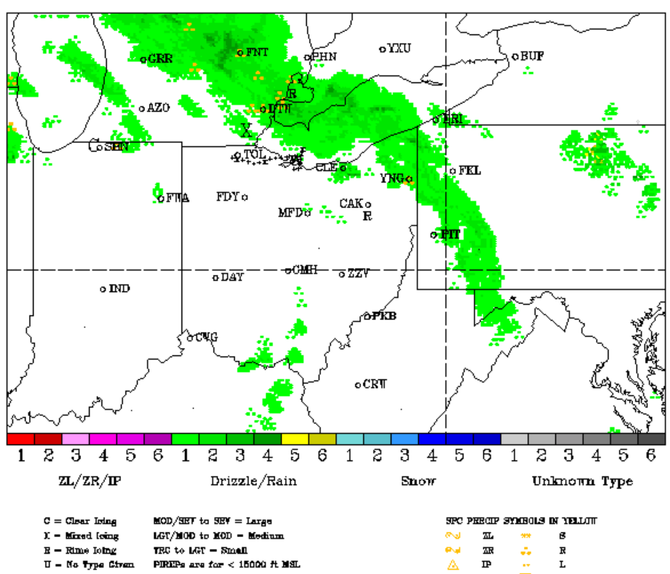
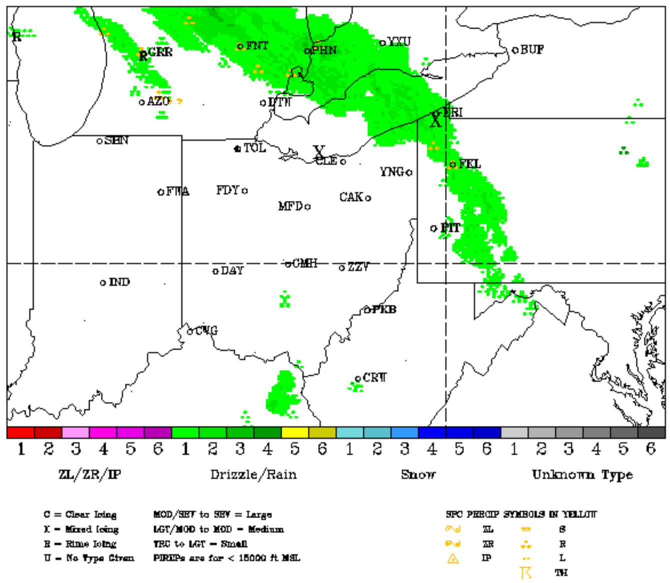


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980227, a) 1400 and b) 1500 UTC.

RADAR DATA PLOT FOR 980227 AT 16 Z



RADAR DATA PLOT FOR 980227 AT 17 Z

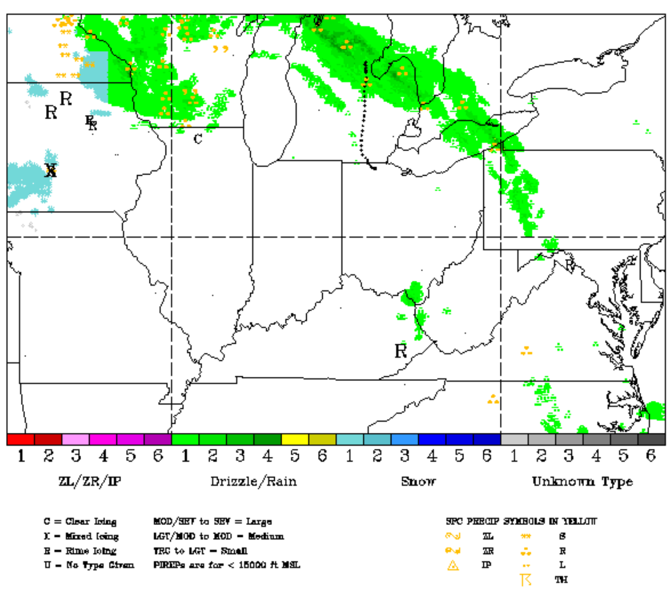
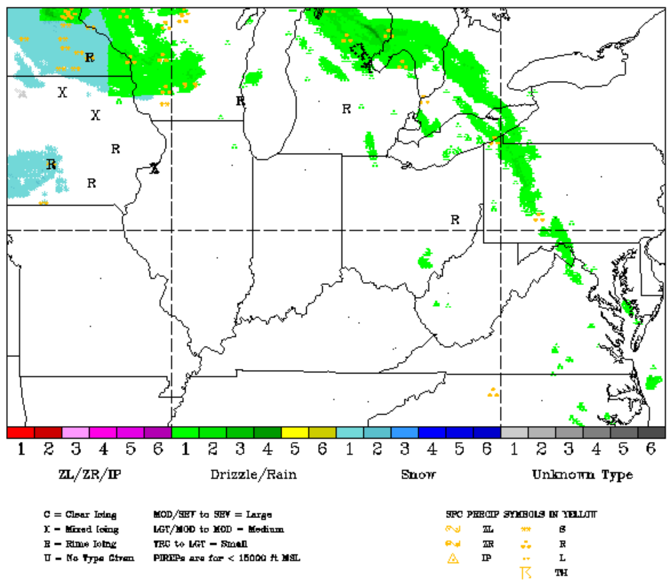


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980227, c) 1600 and d) 1700 UTC.

RADAR DATA PLOT FOR 980227 AT 18 Z



RADAR DATA PLOT FOR 980227 AT 19 Z

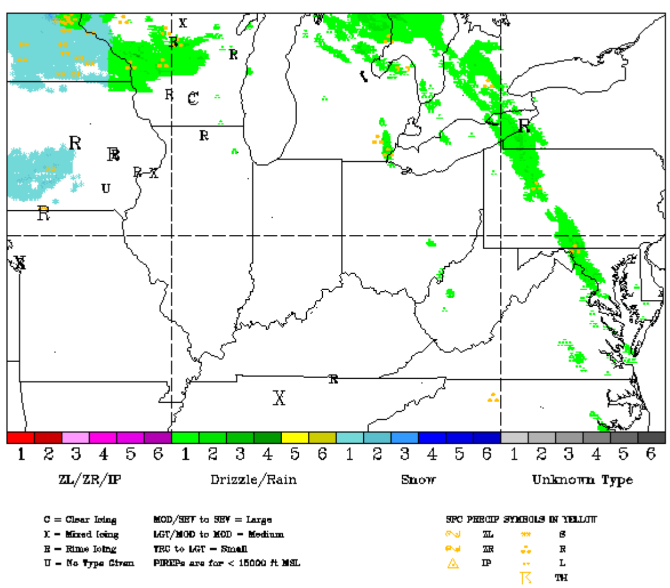
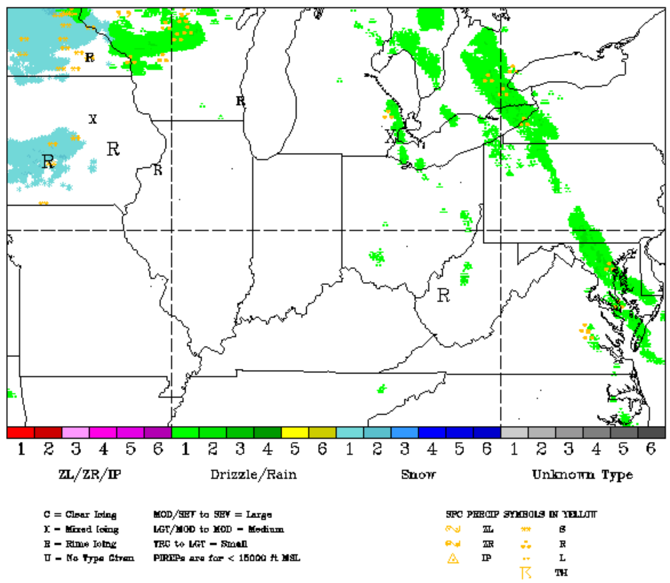


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980227, e) 1800 and f) 1900 UTC.

RADAR DATA PLOT FOR 980227 AT 20 Z



RADAR DATA PLOT FOR 980227 AT 21 Z

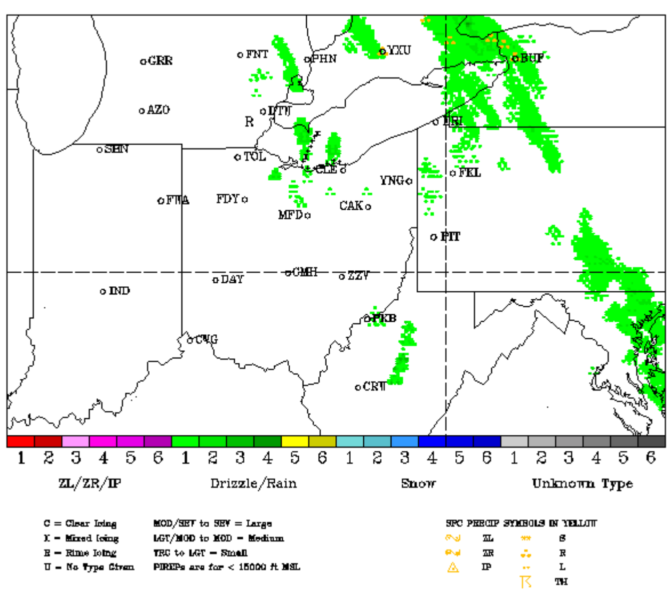
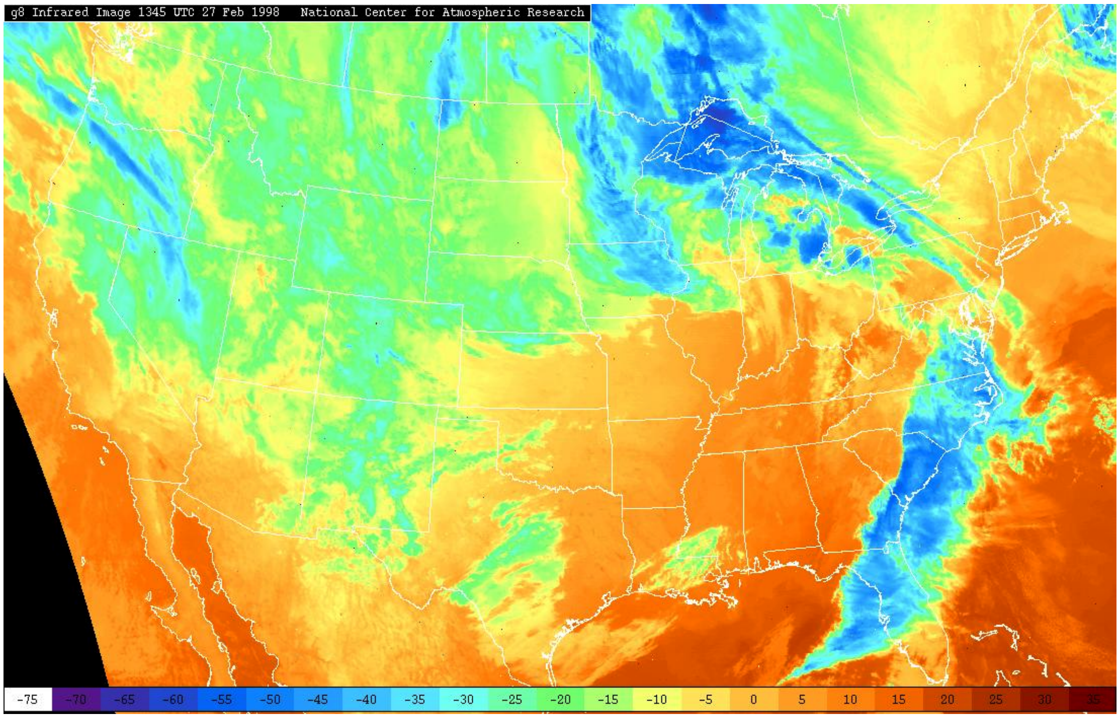


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980227, g) 2000 and h) 2100 UTC.



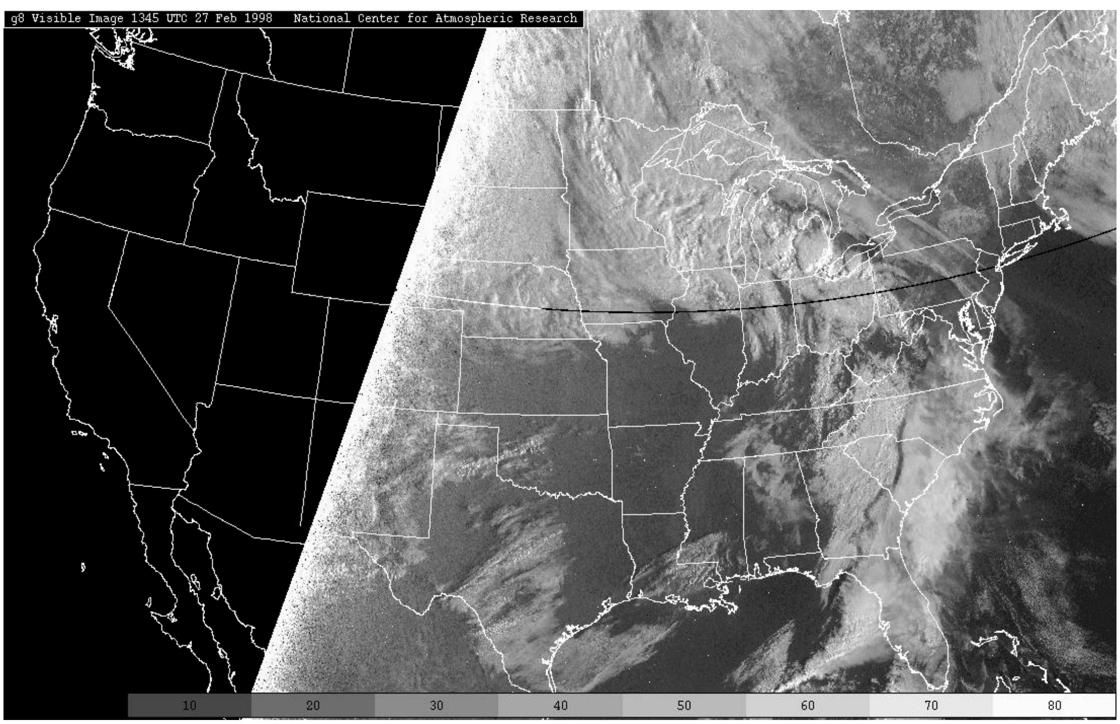
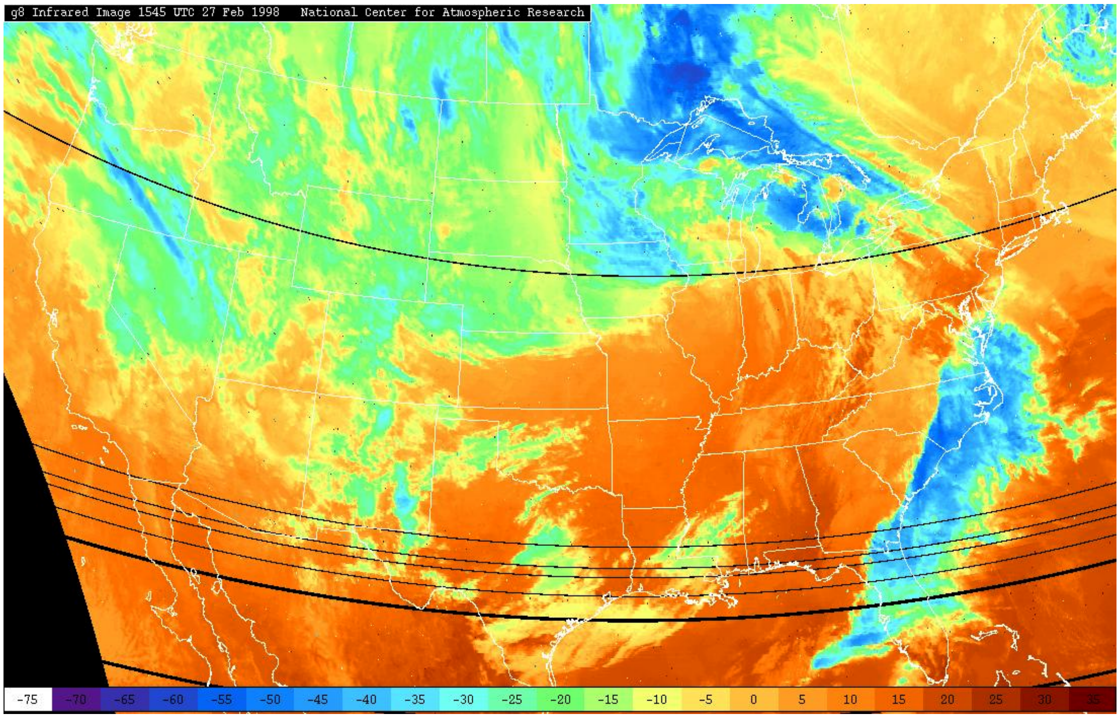


Figure 5 – GOES-8 a) infrared and b) visible satellite images for 980227, 1345 UTC.



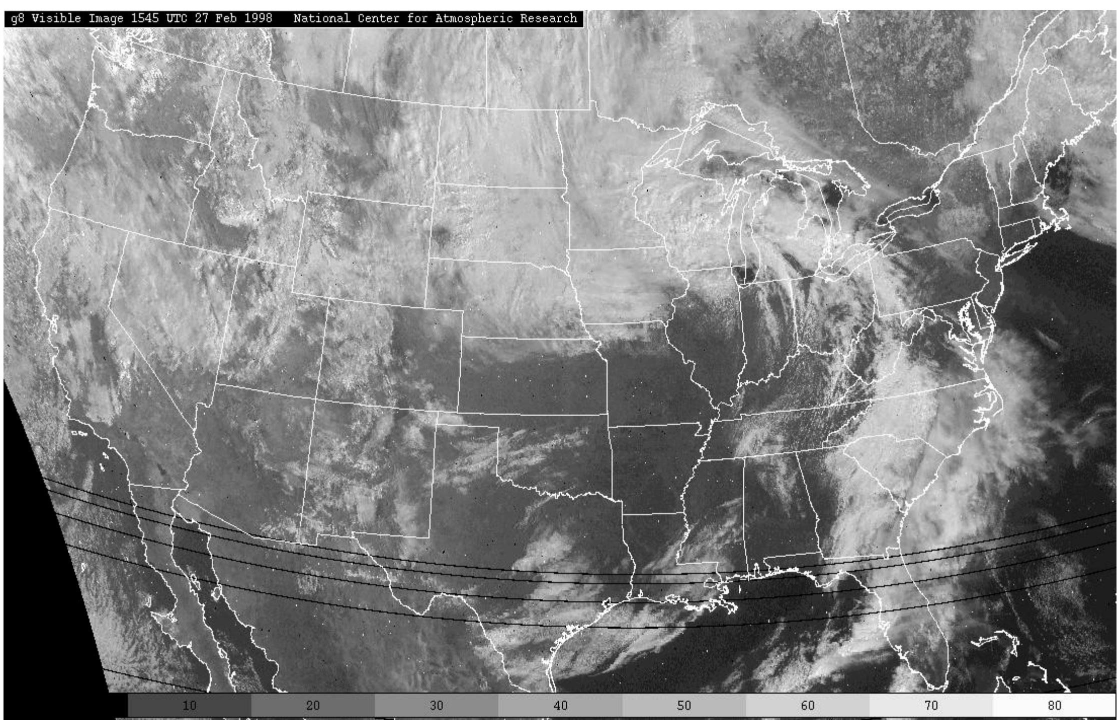
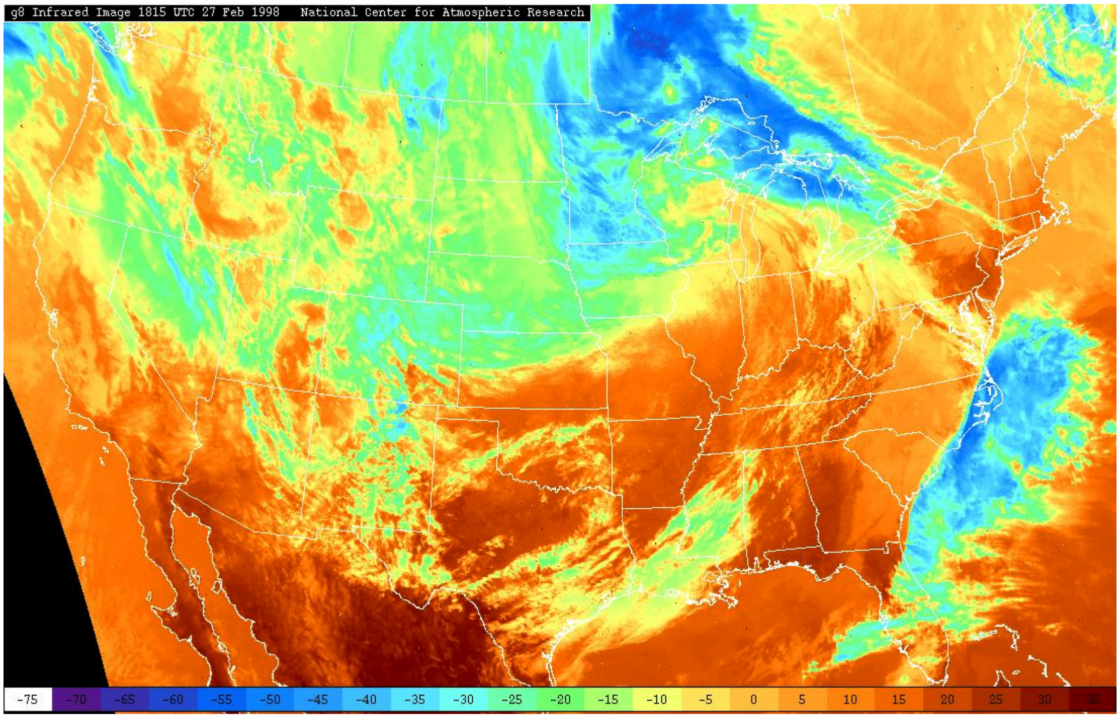


Figure 5 – GOES-8 c) infrared and d) visible satellite images for 980227, 1545 UTC.



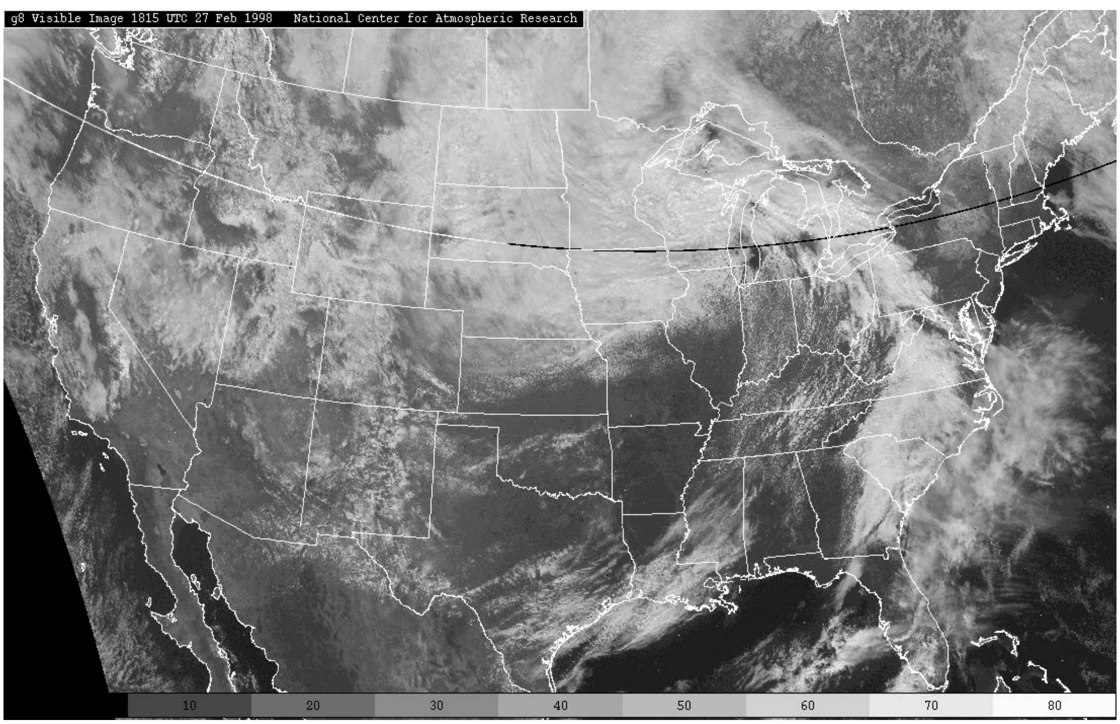
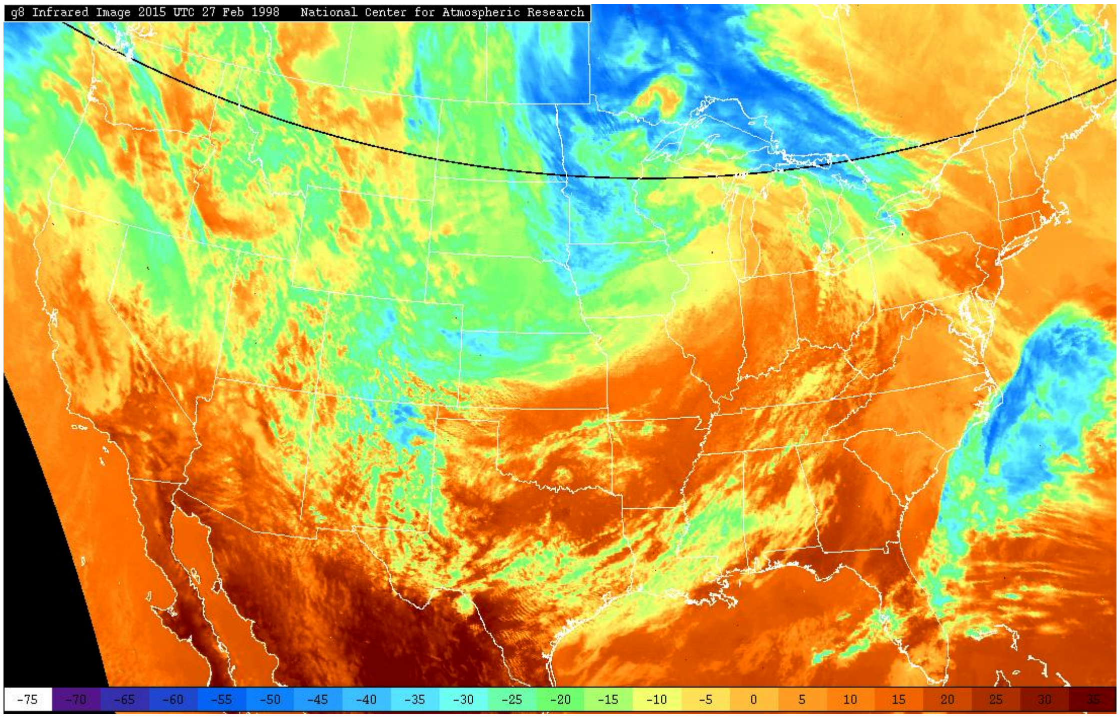


Figure 5 – GOES-8 e) infrared and f) visible satellite images for 980227, 1815 UTC.



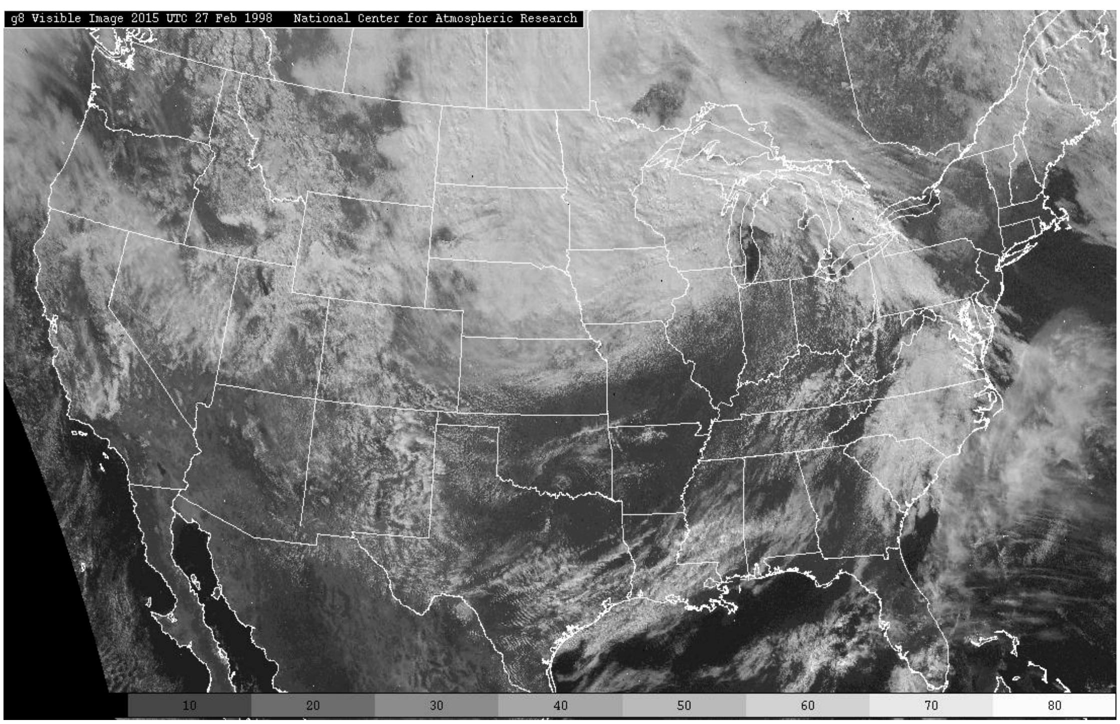
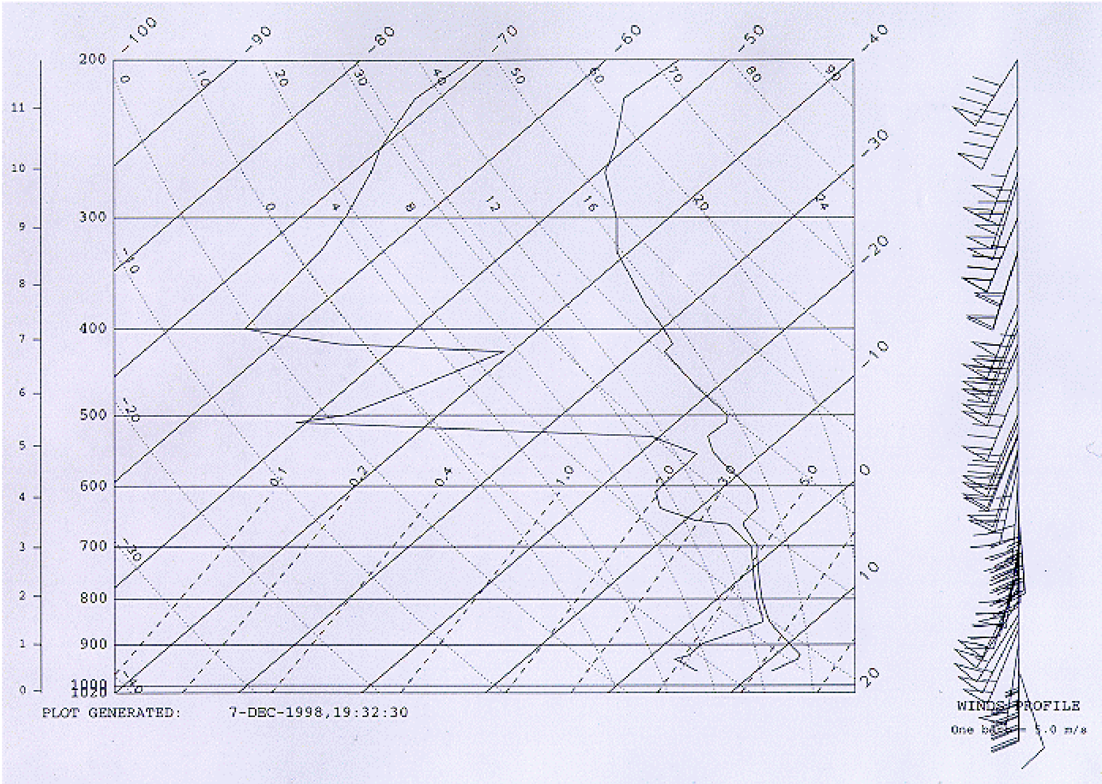


Figure 5 – GOES-8 g) infrared and h) visible satellite images for 980227, 2015 UTC.



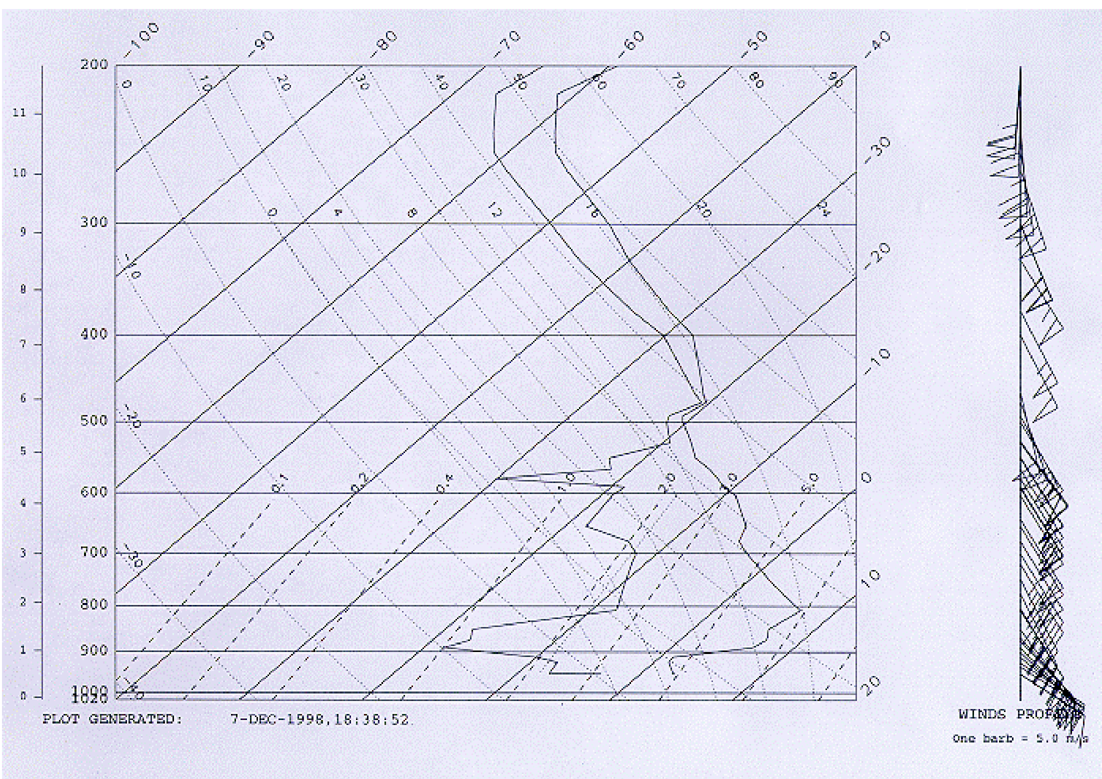
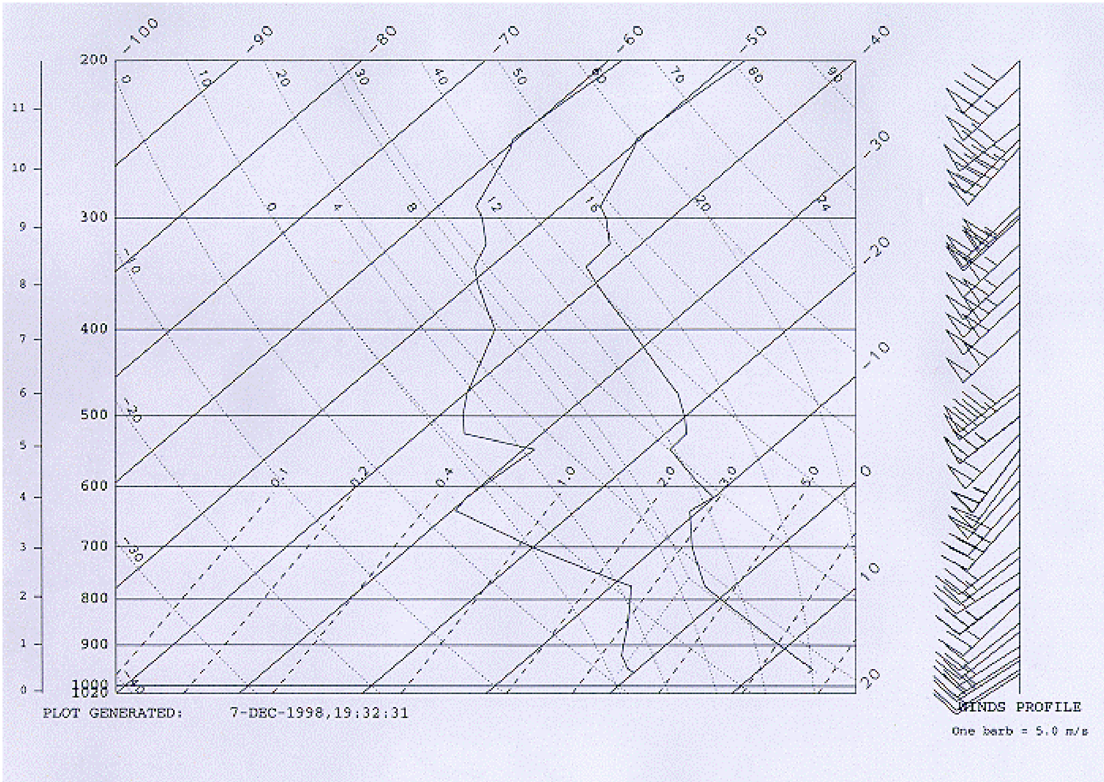


Figure 6 – Balloon-borne soundings from a) Wilmington and b) Alpena MI at 980227, 1200 UTC.



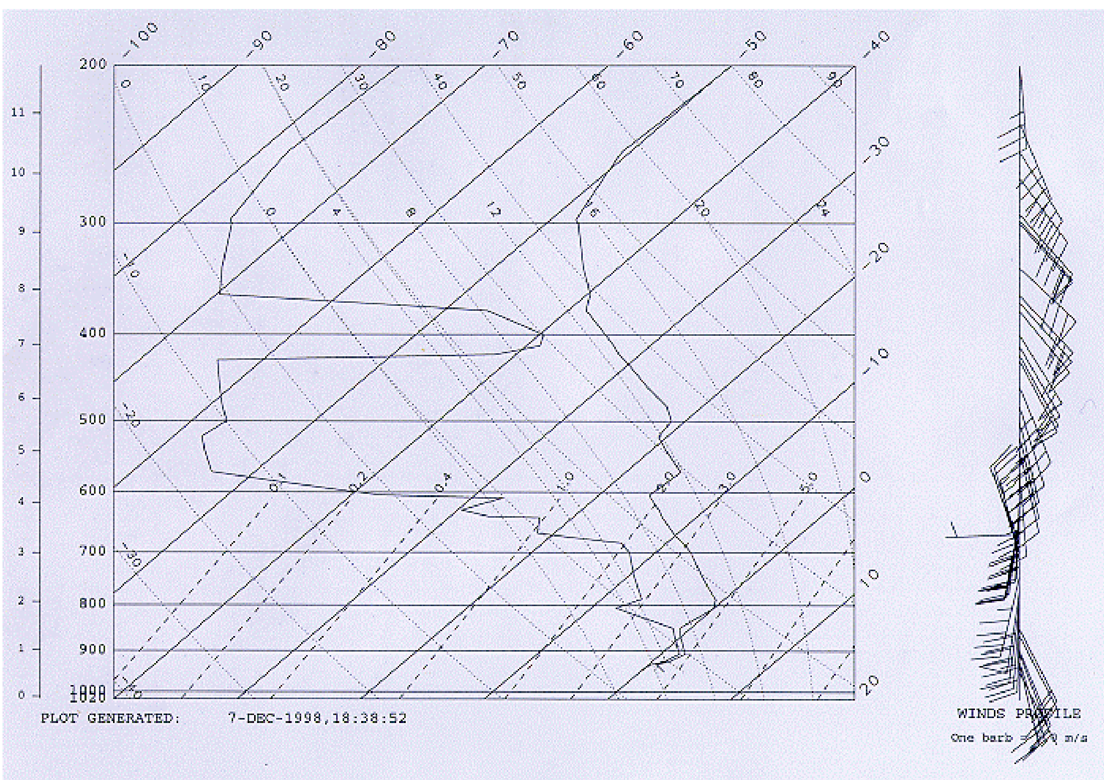
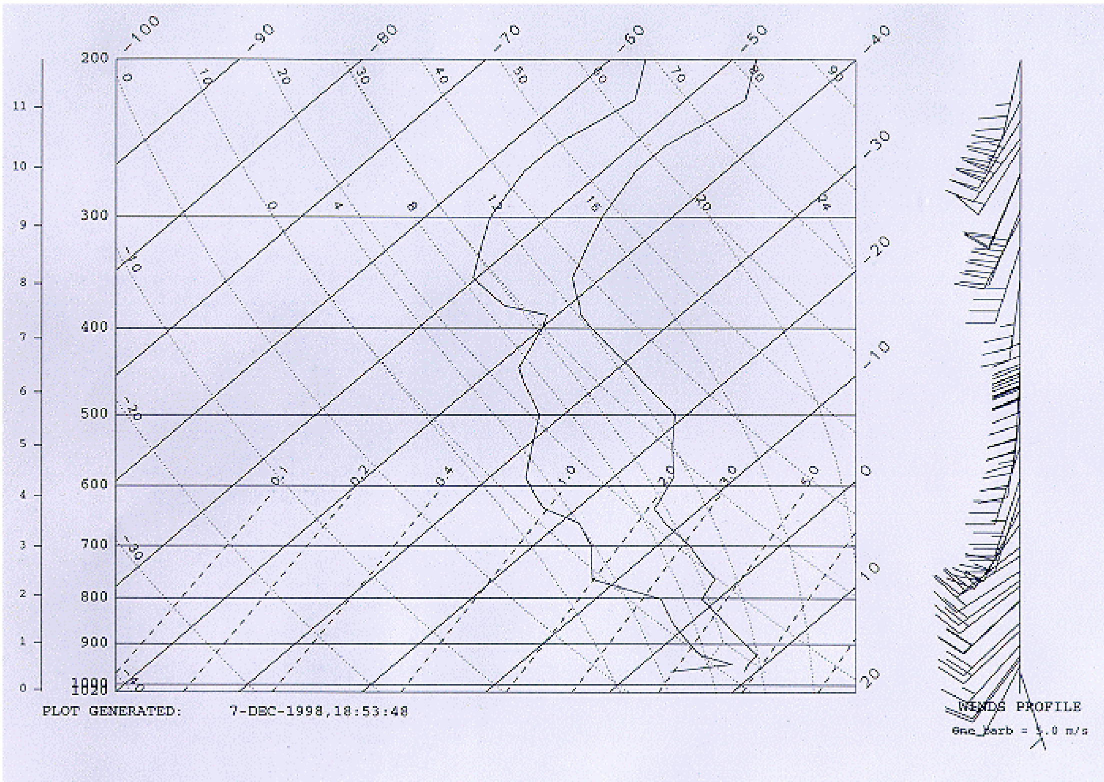


Figure 6 – Balloon-borne soundings from c) Wilmington and d) Alpena MI at 980228, 0000 UTC.



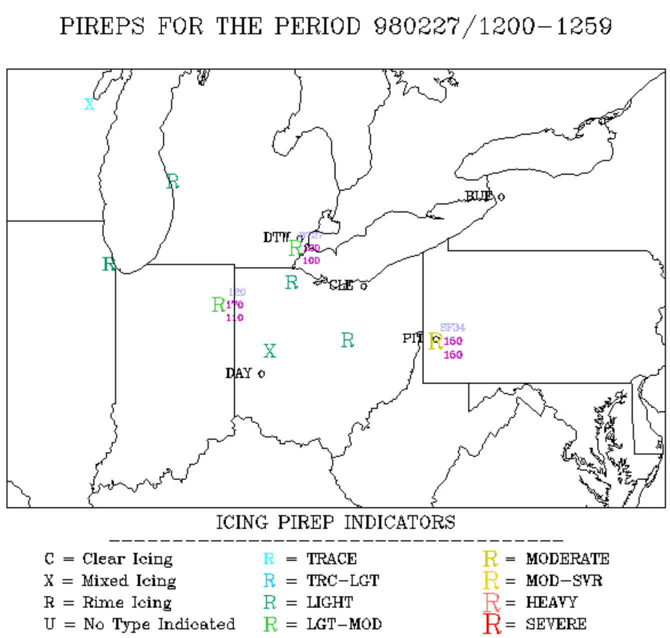
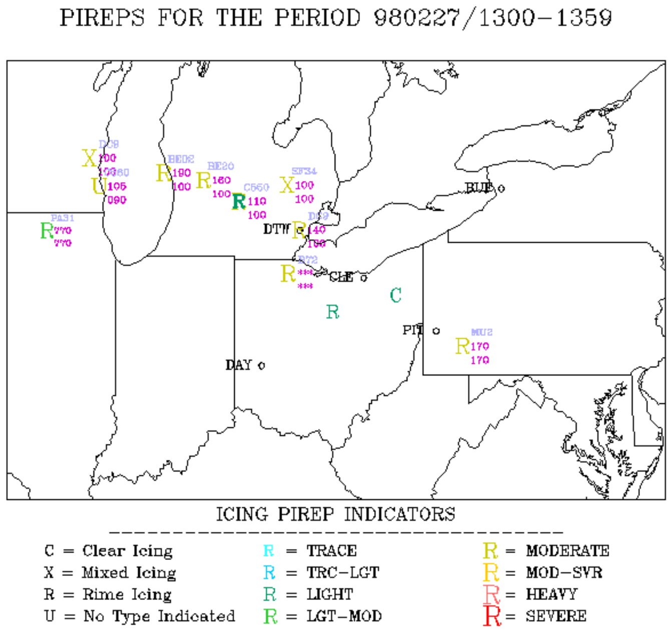


Figure 6 – Balloon-borne soundings from e) Detroit at 980228, 0000 UTC.
Figure 7 – Pilot reports of icing for 980227, a) 1200-1259 UTC.



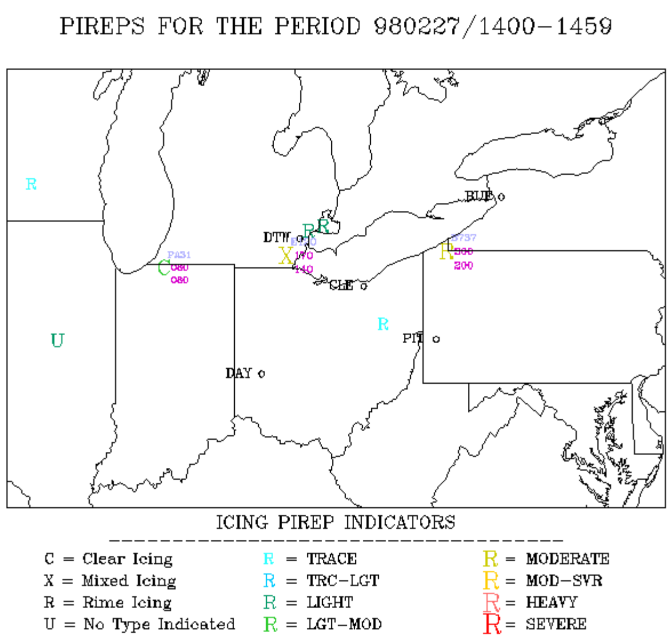
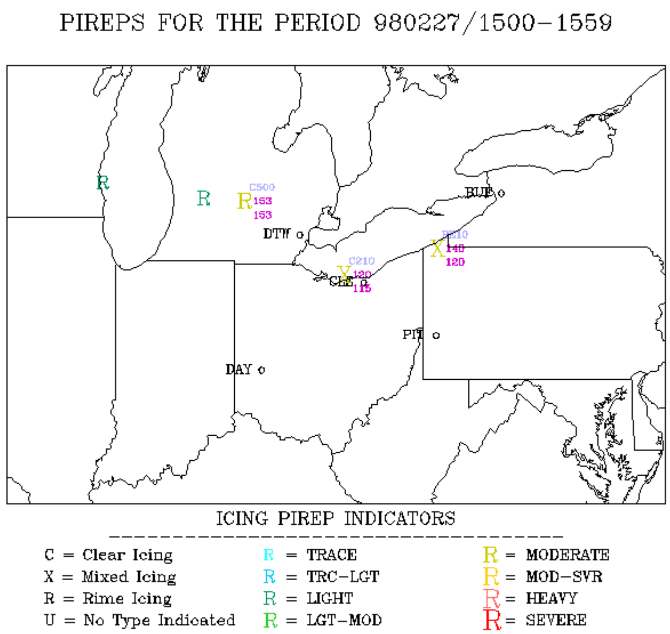


Figure 7 – Pilot reports of icing for 980227, b) 1300-1359 and c) 1400-1459 UTC.



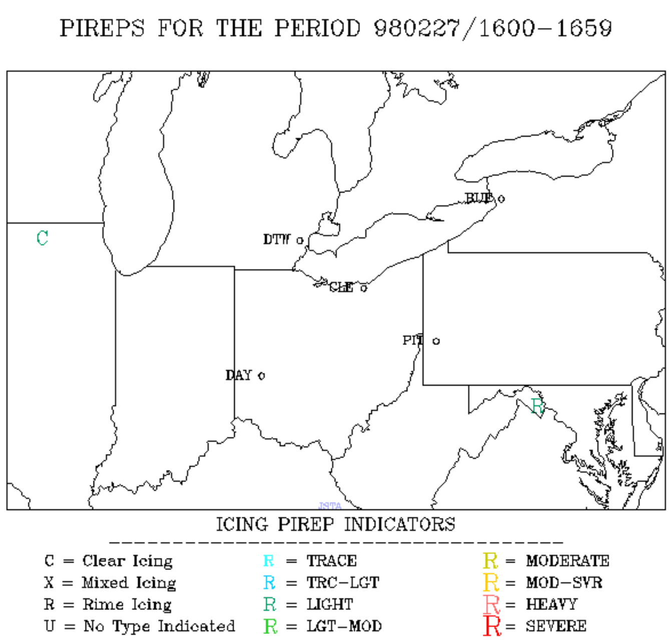
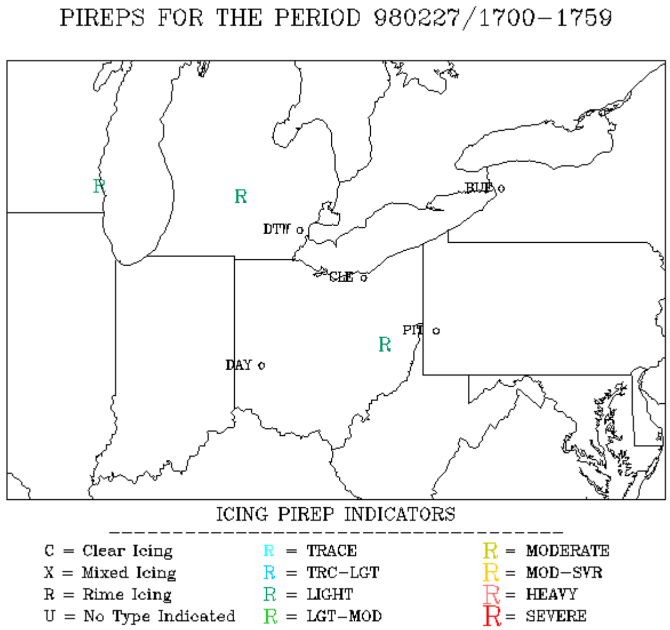


Figure 7 – Pilot reports of icing for 980227, d) 1500-1559 and e) 1600-1659 UTC.



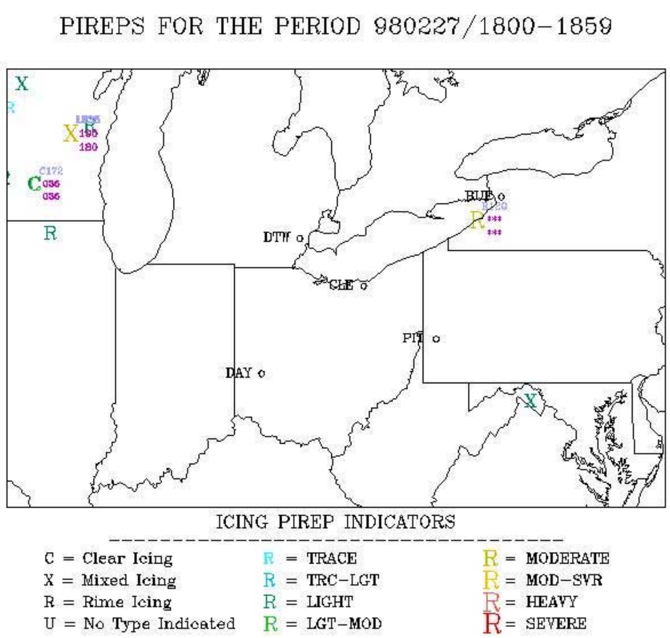
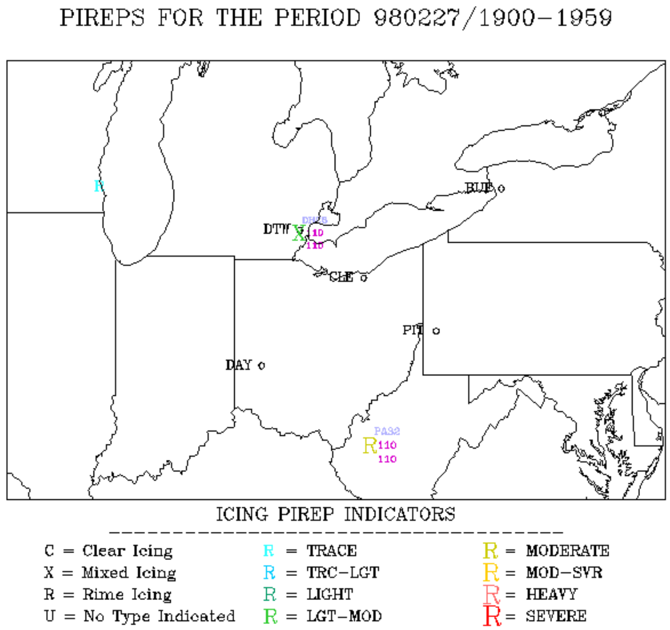


Figure 7 – Pilot reports of icing for 980227, f) 1700-1759 and g) 1800-1859 UTC.



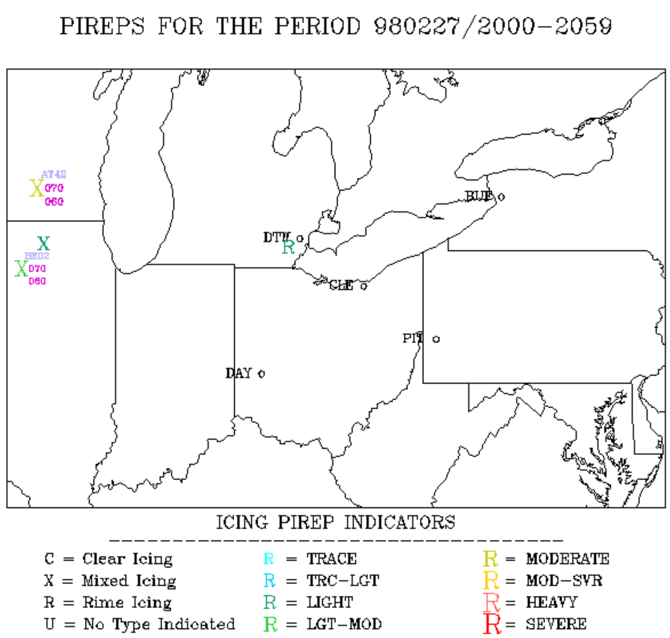


Figure 7 – Pilot reports of icing for 980227, h) 1900-1959 and i) 2000-2059 UTC.

March 2, 1998

Flight #1—Over Akron/Youngstown, OH, and Parkersburg, WV, from 1436 to 1633 UTC.
Flight #2—Over Parkersburg, WV, and Zanesville and Akron/Youngstown, OH, from 1824 to 1958 UTC.

Brief overview

On this day, two flights were made into small-drop, mixed phase, and snow within and around areas of surface precipitation. During the first flight, snow was encountered at 5500' over Cleveland. Snow and layers of small-drop clouds with LWC < 0.05 were present up to 11,000' over eastern Ohio. Areas with inconsistent LWC up to 0.3 were observed along the Ohio-West Virginia border. Snow and mixed-phase clouds existed from 13,200' down to 1700', with rain below that to the surface at Parkersburg. The freezing level was at 2300' there. Conditions were very similar during the second flight. Small areas of LWC as high as 0.4 were observed, but LWC was between 0.0 and 0.15 during most of this flight.

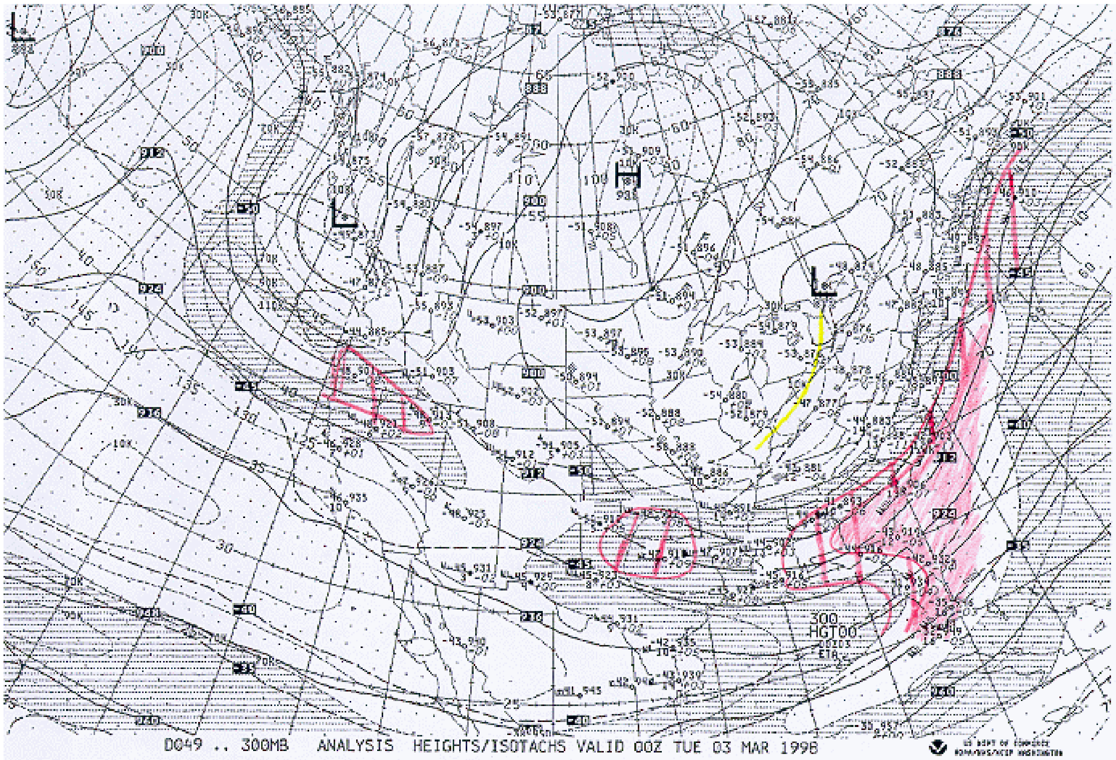
Relevant weather features

At 0000 on 3 March, a weak, closed 300 mb low was centered along the Ontario/Quebec border (Fig. 1). A trough ran southwestward from the low across northwestern Ohio to southern Illinois. At 500 mb, a weak, secondary low over Kentucky was at the southern end of the trough, which cut through central Ohio. Moist air was present over the area surrounding and to the north of Lakes Erie and Ontario. Slightly drier, but nearly saturated air covered much of Ohio, and to the south and east. A pocket of cool air was co-located with the trough axis. At 700 mb, the cool pocket remained centered on the trough which ran from northern Arkansas through northwestern Ohio to a closed low just north of Lake Huron. Saturated air surrounded the trough and low, except for a swath of dry air from Detroit to New England. Cold advection preceded the trough, thanks to westerly and southwesterly winds emanating from the cool pocket, while northwesterly winds advected in warm air behind the trough. The pattern was similar at 850 mb, except that the cool pocket was not as well-defined, and the warm advection behind the trough was more confined. West and northwest winds at 850 mb and the surface (Fig. 2) brought upslope conditions to the western side of the Appalachians in Pennsylvania and West Virginia. Overcast skies and patchy light rain, drizzle, and snow fell across these areas between 1500 and 2100 UTC (Fig. 3). This occurred well ahead of the surface trough moving across Michigan, and just behind the secondary trough that was analyzed as through western Pennsylvania at 1500 UTC.

Satellite imagery taken at 1415 UTC (Fig. 4) showed fairly cool clouds (CTTs near -20C) over southeastern Ohio, and bordering portions of Pennsylvania and West Virginia. Large breaks of clear sky existed in the surrounding areas. The Ohio/Pennsylvania/West Virginia clouds expanded and warmed slightly by 1615 UTC, but most of them still had CTTs near -15C. The clouds continued to expand and started to cool again by 1815 UTC, increasing the likelihood of significant amounts of ice crystals within them.

The 1200 and 0000 UTC Pittsburgh soundings (Fig. 5) showed the relatively deep, cool

(CTTs < -20C) nature of the clouds there. The Detroit soundings ascended through pockets of somewhat warmer clouds. The 1200 UTC Wilmington sounding went up in one of the areas with breaks in the cloud cover, while the 0000 UTC sounding passed through some of the cooler clouds that moved into the state during the day. PIREPs of icing were scattered, and rather light early in the day (Fig. 6). Some moderate severity rime and mixed icing was reported across the region after 1500 UTC, especially over Michigan and Wisconsin. In the area of the flights, most icing was reported at altitudes between 5,000' and 10,000'.



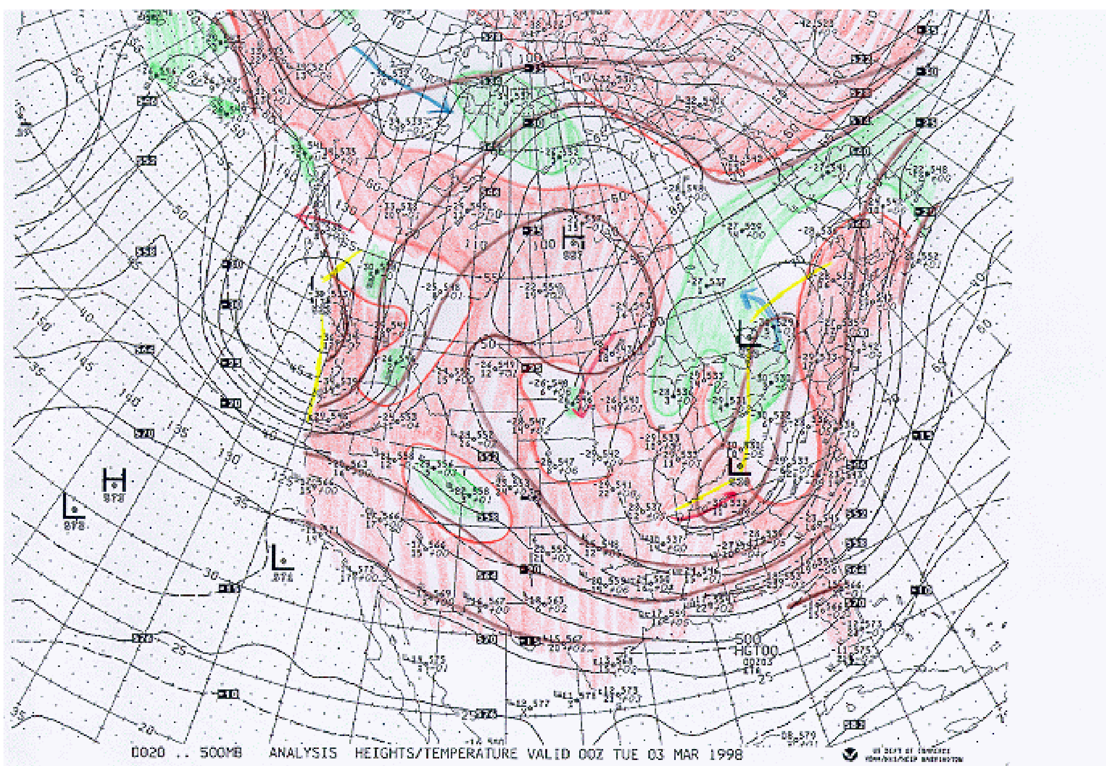
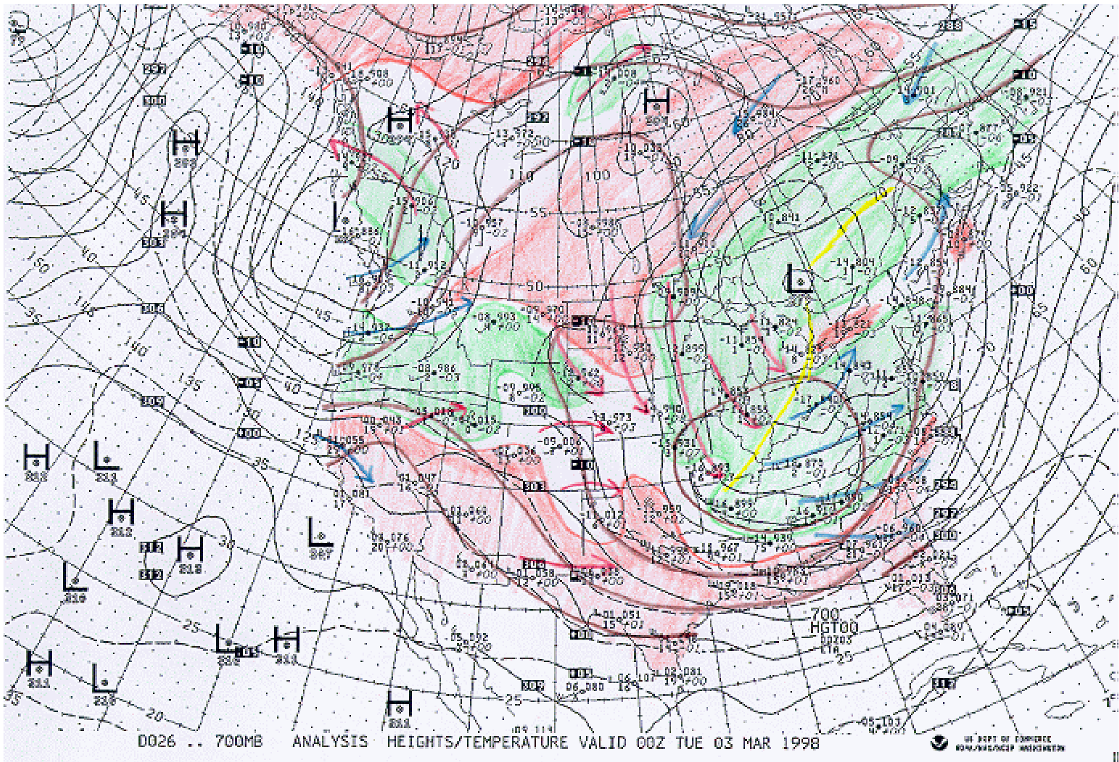


Figure 1 – Upper-air charts for 980303, 0000 UTC at a) 300 and b) 500 mb.



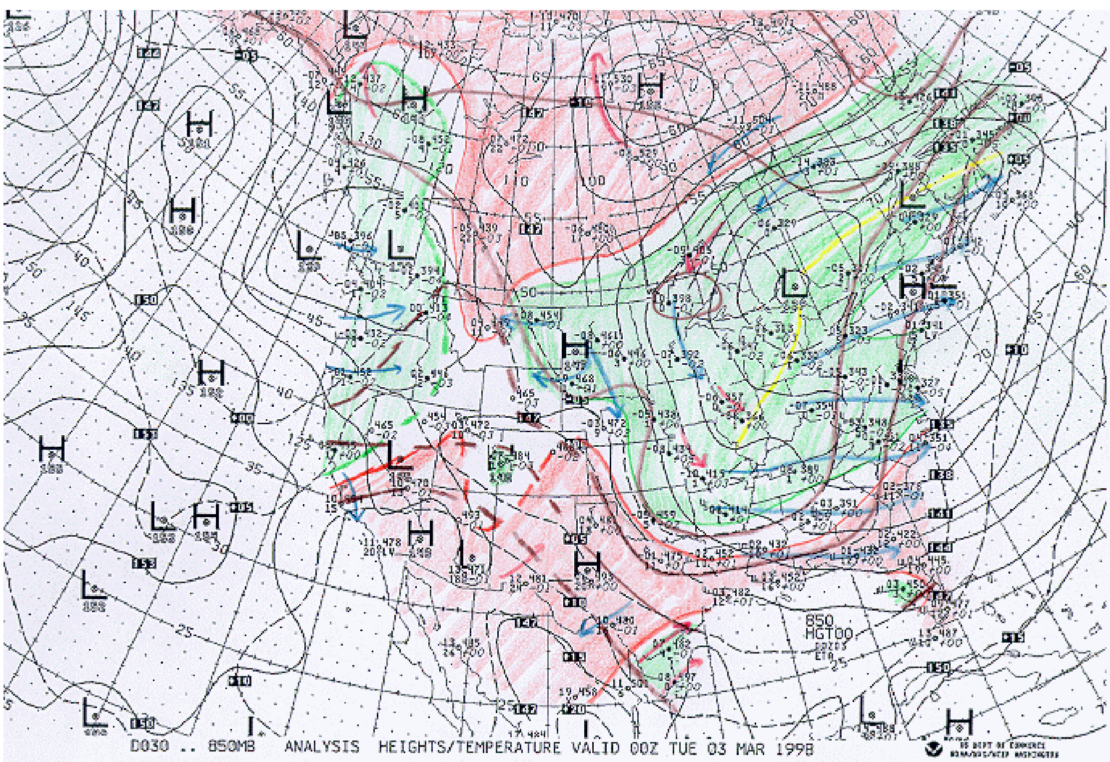


Figure 1 – Upper-air charts for 980303, 0000 UTC at c) 700 and d) 850 mb.

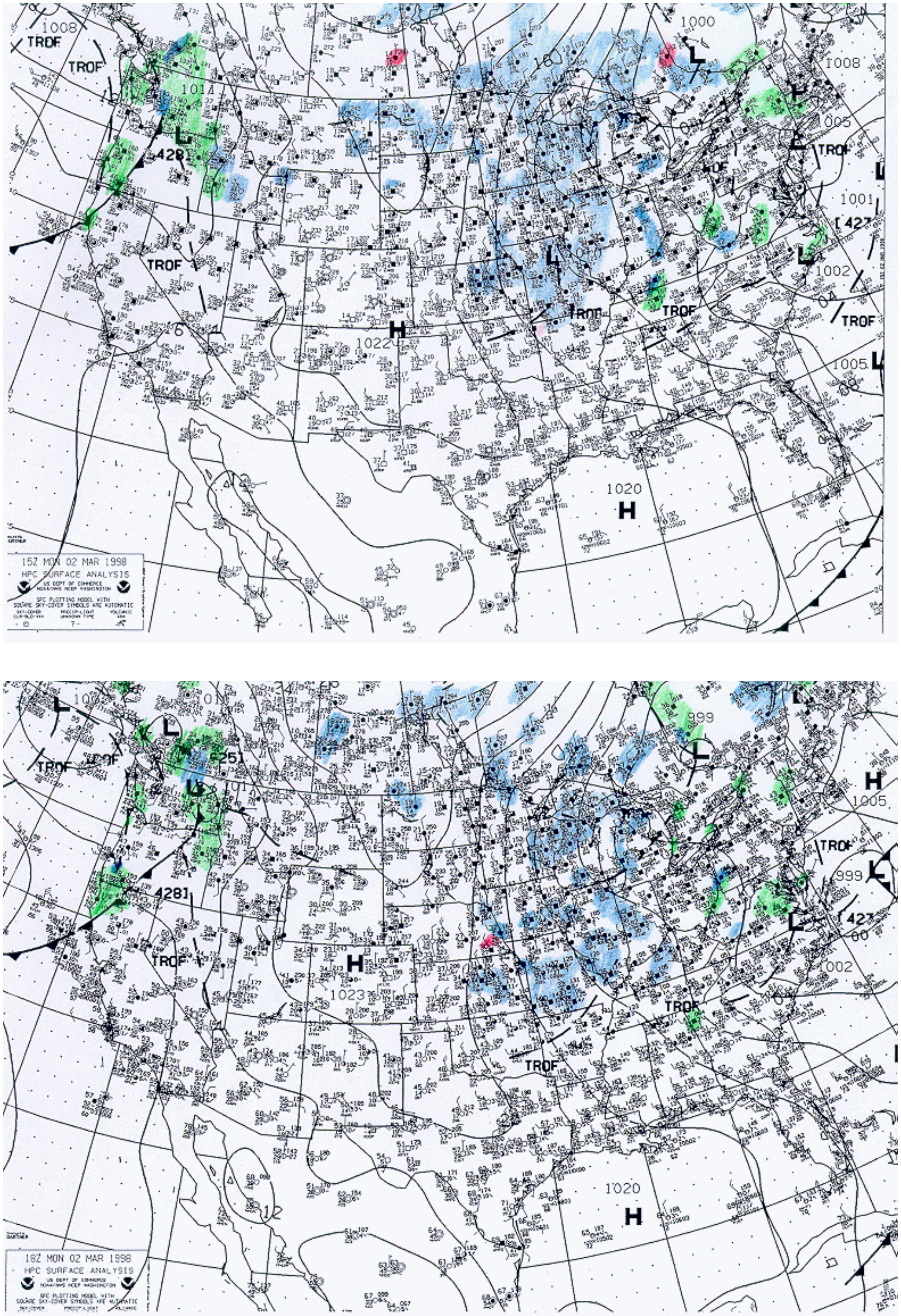
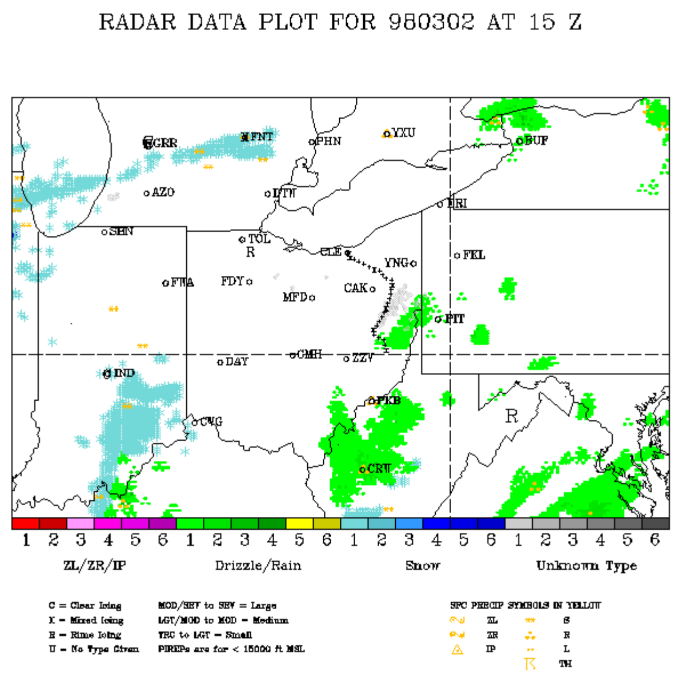


Figure 2 – Surface charts for 980302, a) 1500 and b) 1800 UTC.



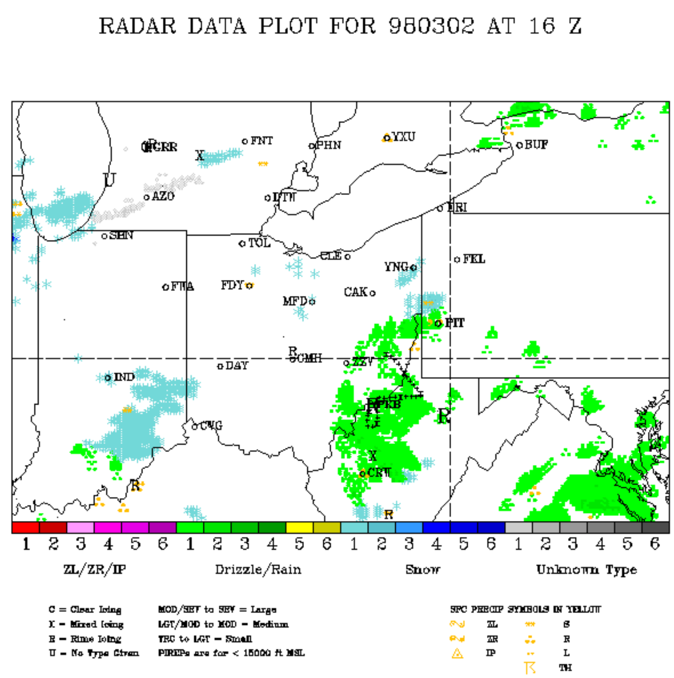
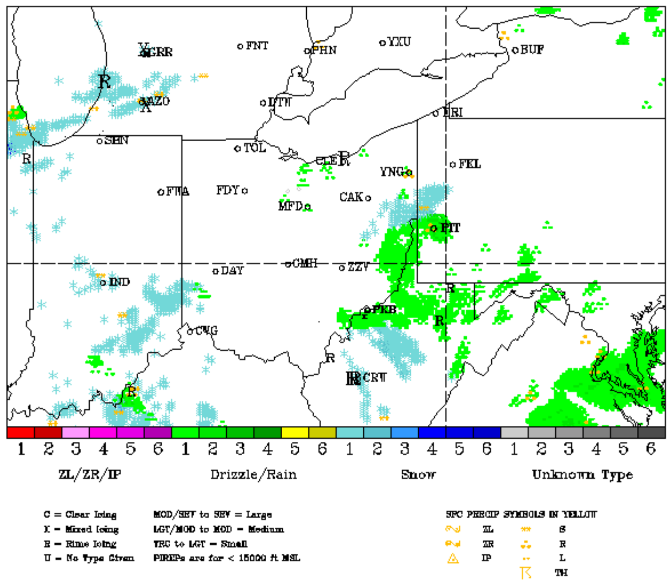


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980302, a) 1500 and b) 1600 UTC.

RADAR DATA PLOT FOR 980302 AT 17 Z



RADAR DATA PLOT FOR 980302 AT 18 Z

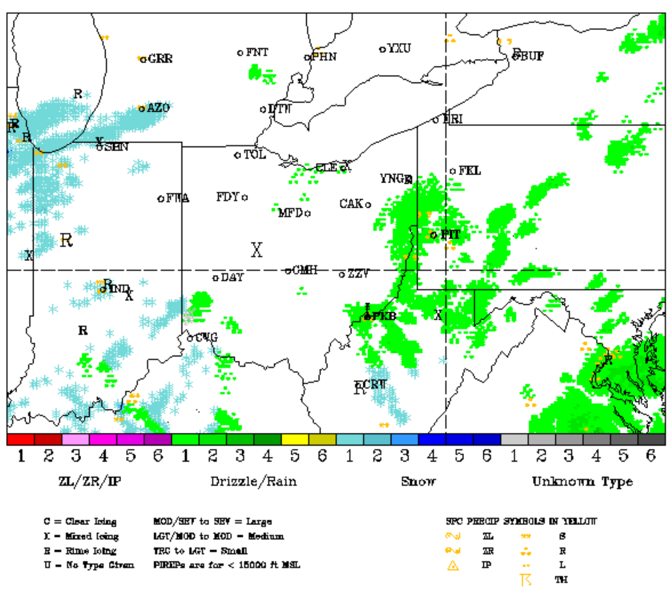
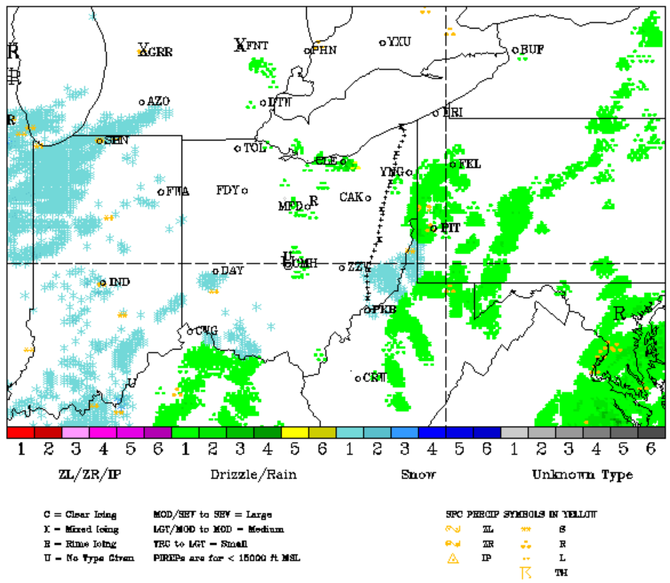


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980302, c) 1700 and d) 1800 UTC.

RADAR DATA PLOT FOR 980302 AT 19 Z



RADAR DATA PLOT FOR 980302 AT 20 Z

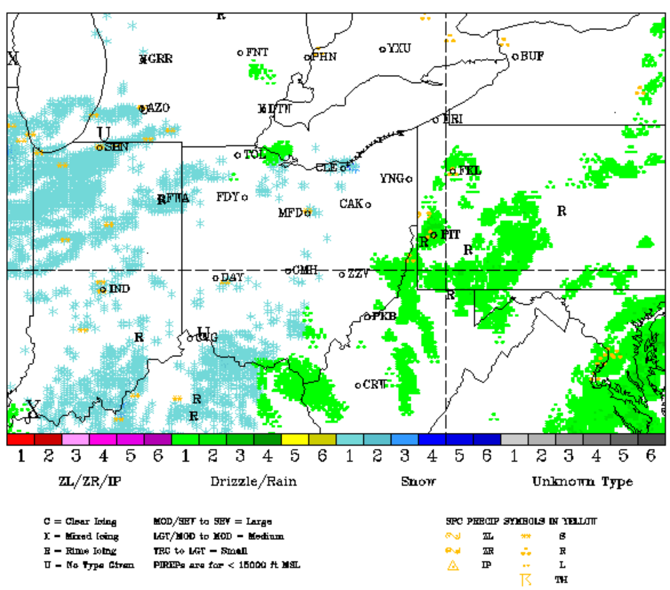
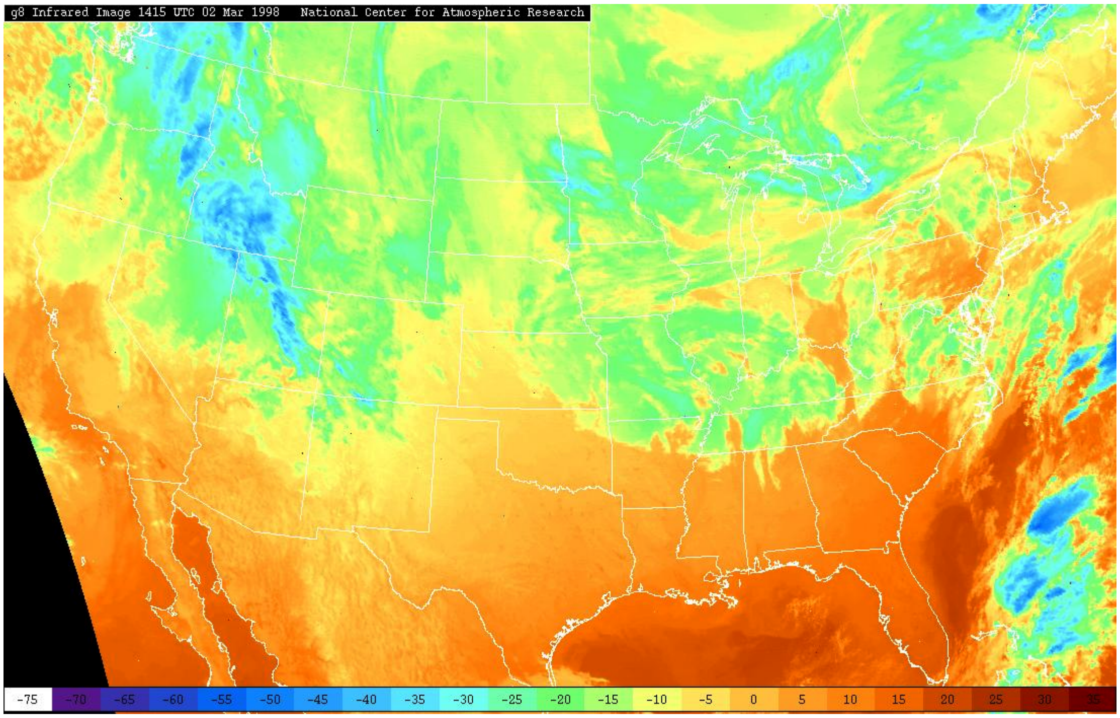


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980302, e) 1900 and f) 2000 UTC.



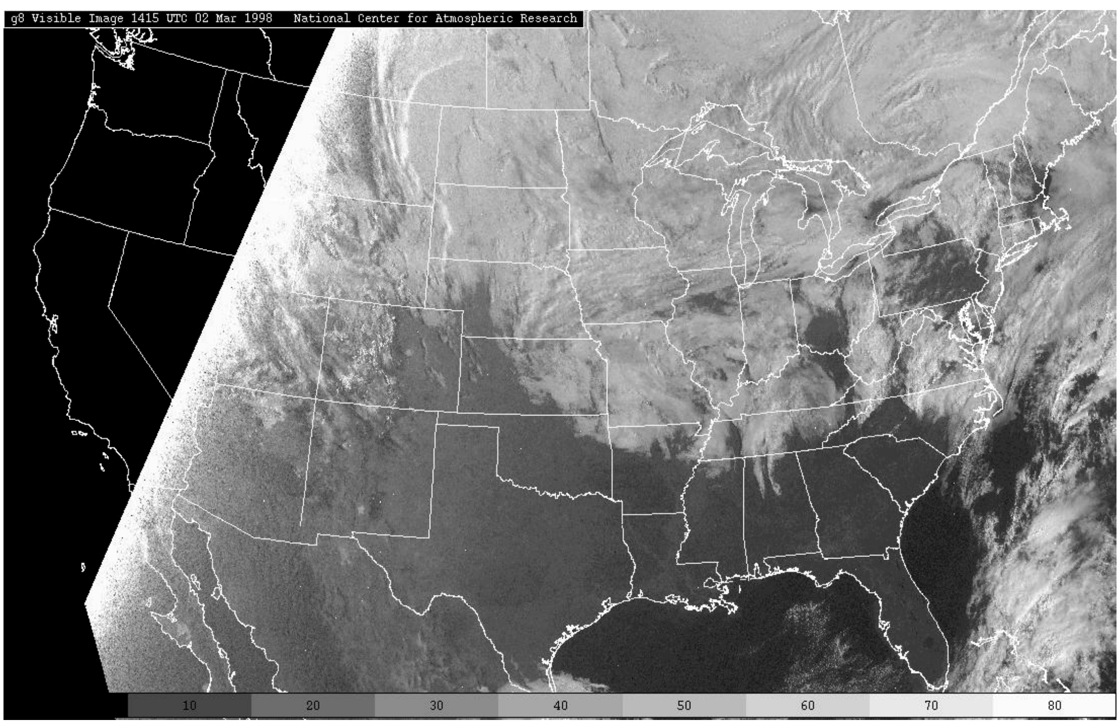
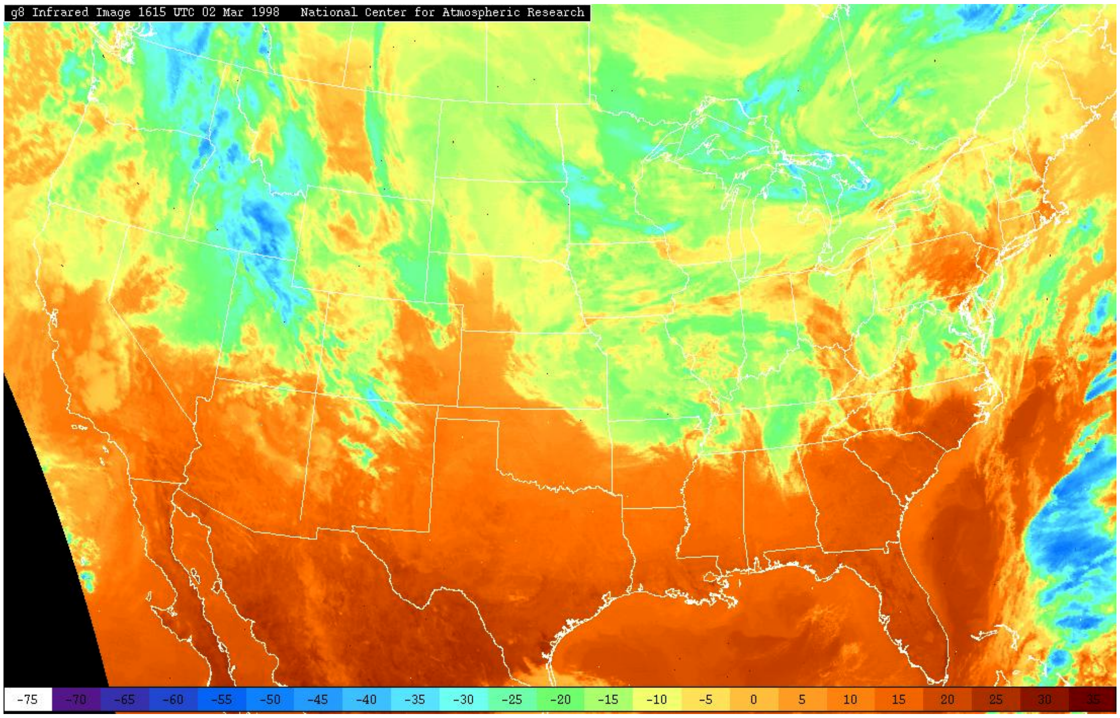


Figure 4 – GOES-8 a) infrared and b) visible satellite image for 980302, 1415 UTC.



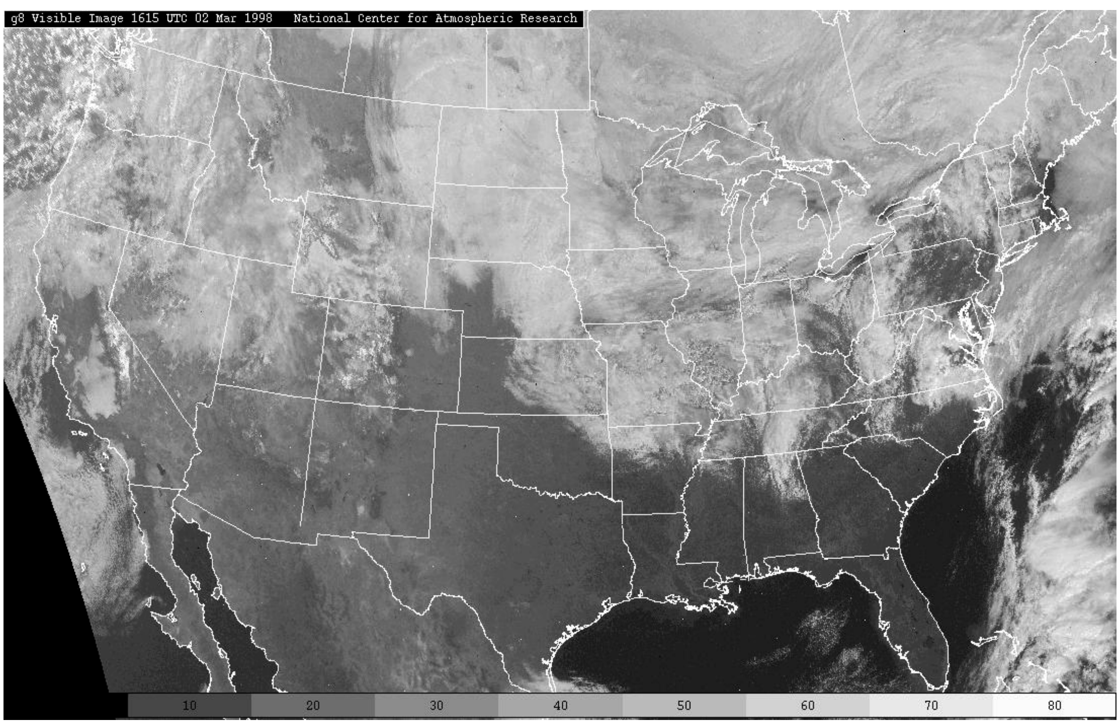
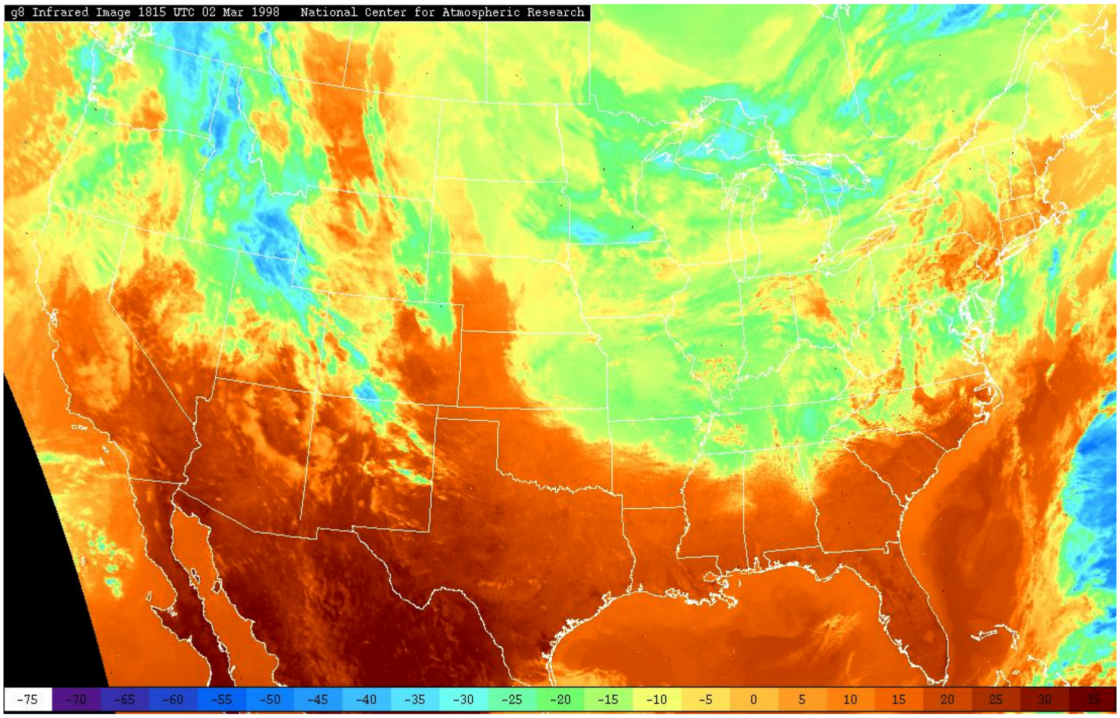


Figure 4 – GOES-8 c) infrared and d) visible satellite image for 980302, 1615 UTC.



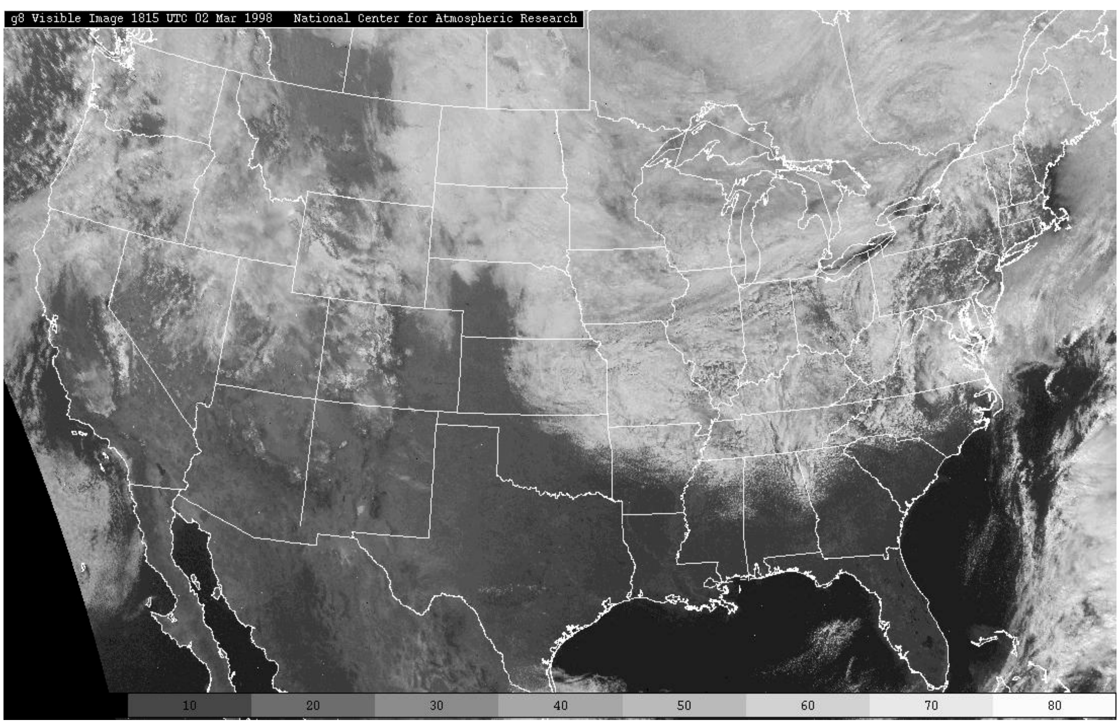
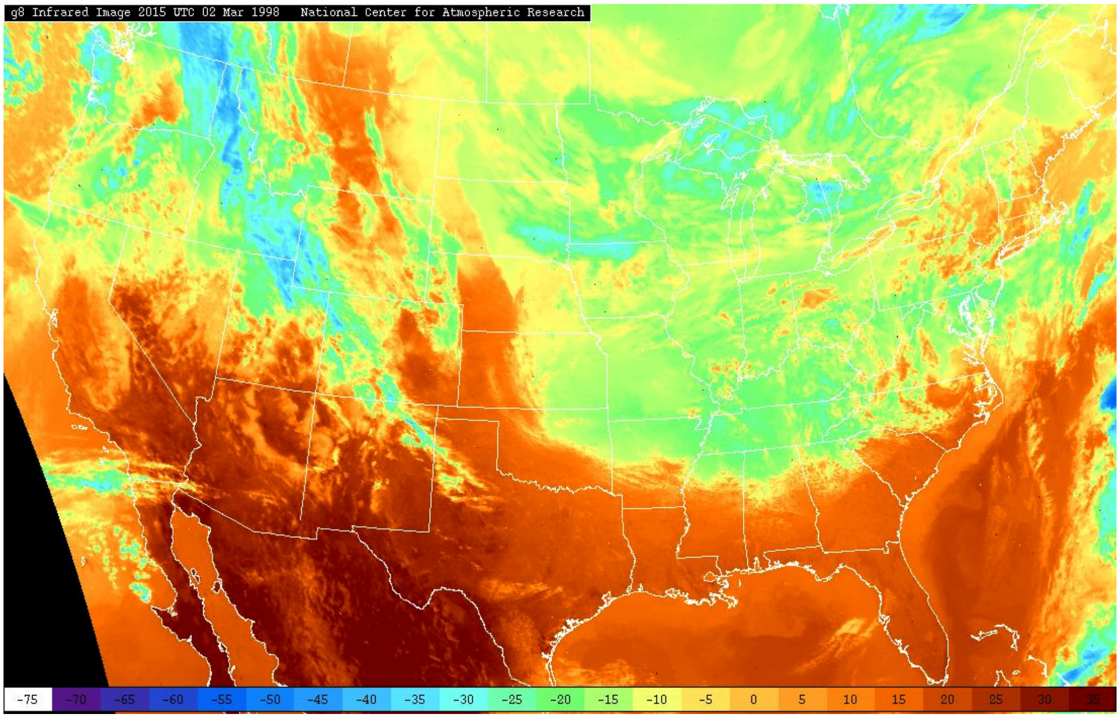


Figure 4 – GOES-8 e) infrared and f) visible satellite image for 980302, 1815 UTC.



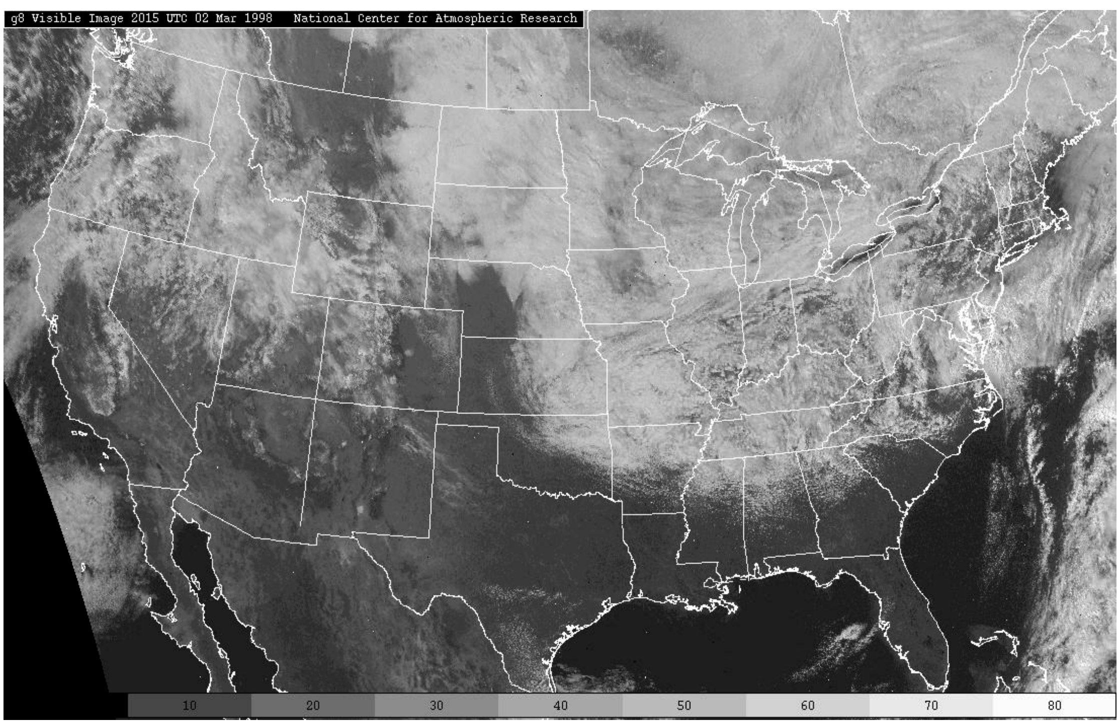
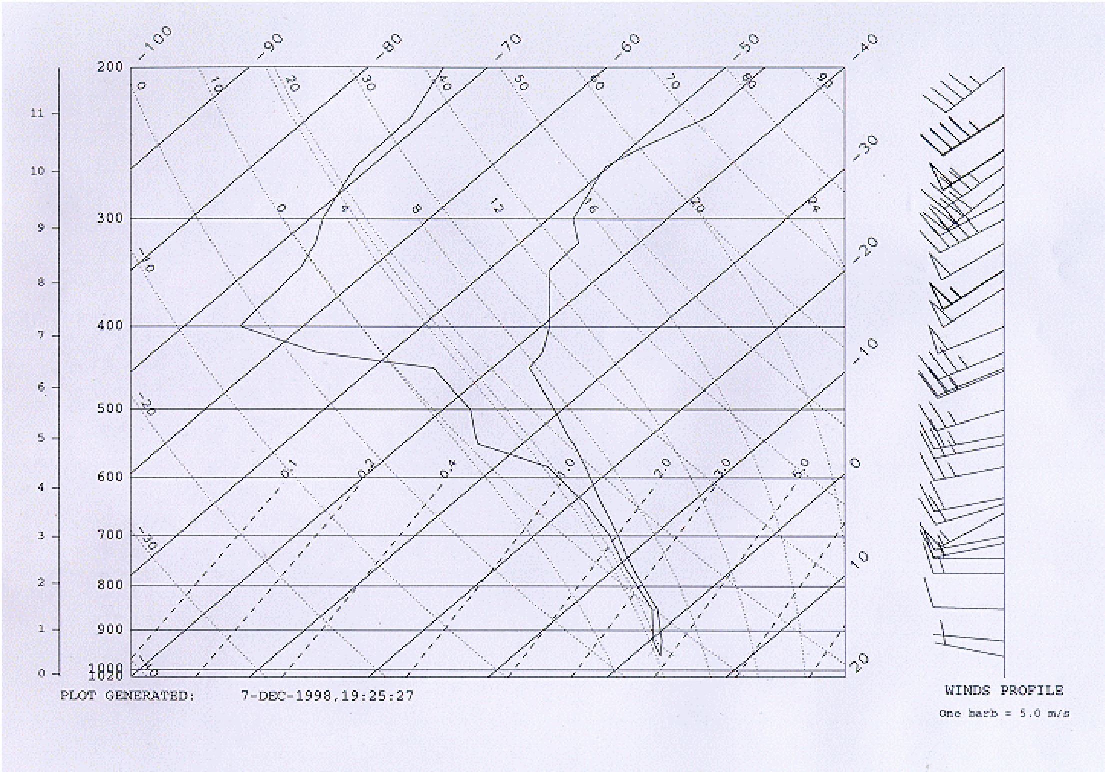


Figure 4 – GOES-8 g) infrared and h) visible satellite image for 980302, 2015 UTC.



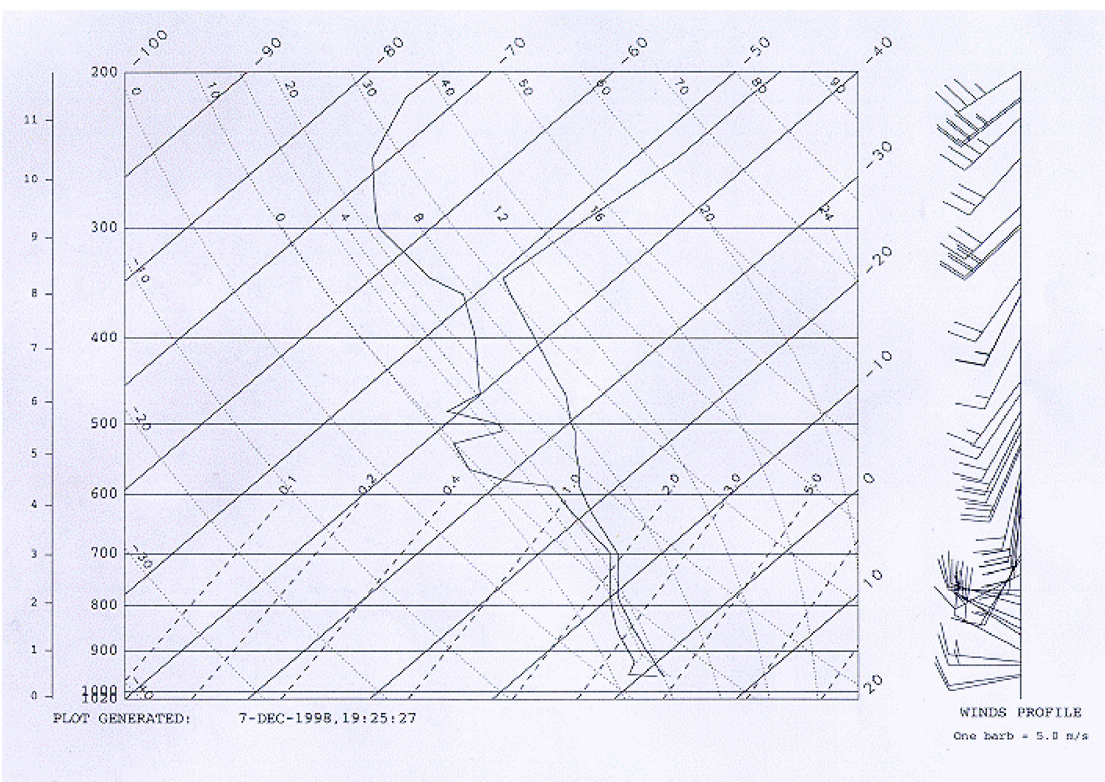
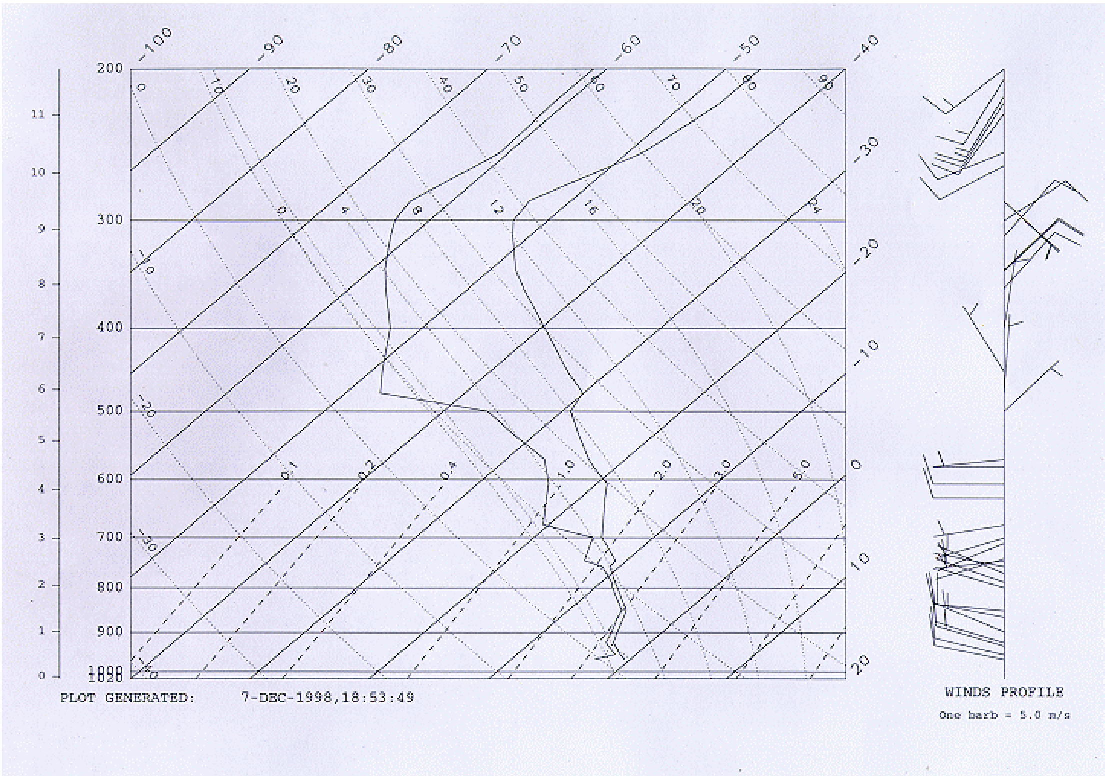


Figure 5 – Balloon-borne soundings from Pittsburgh at a) 980302, 1200 and b) 980303, 0000 UTC.



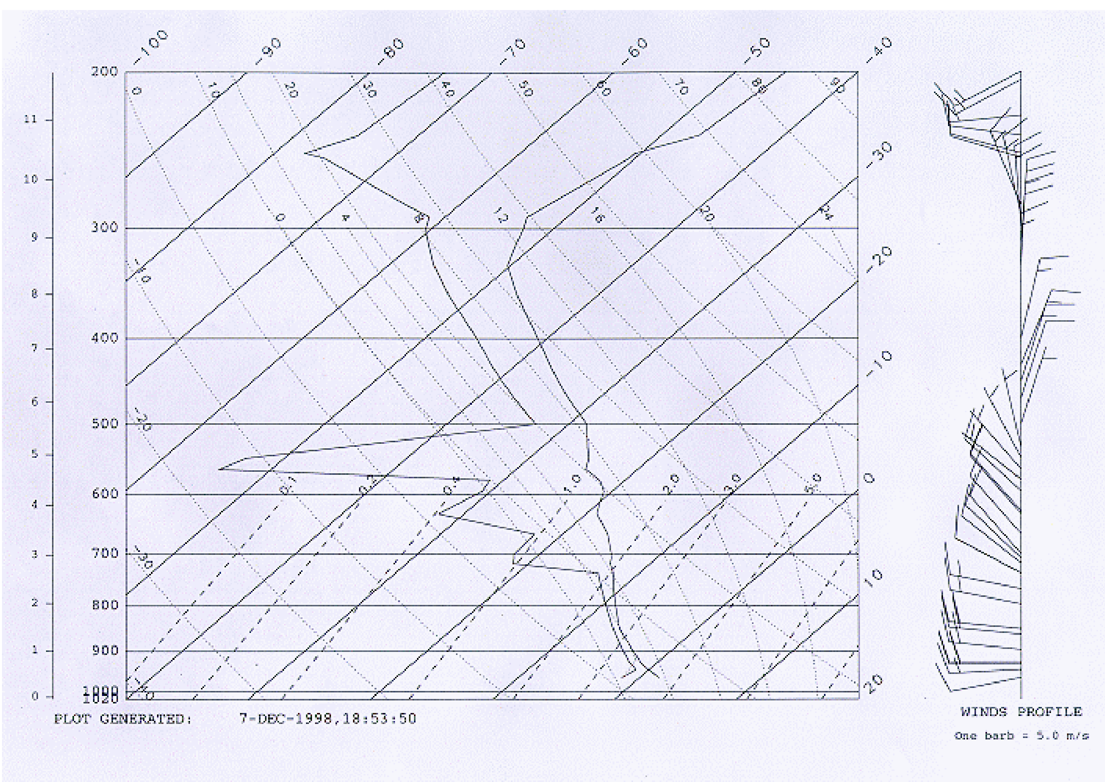
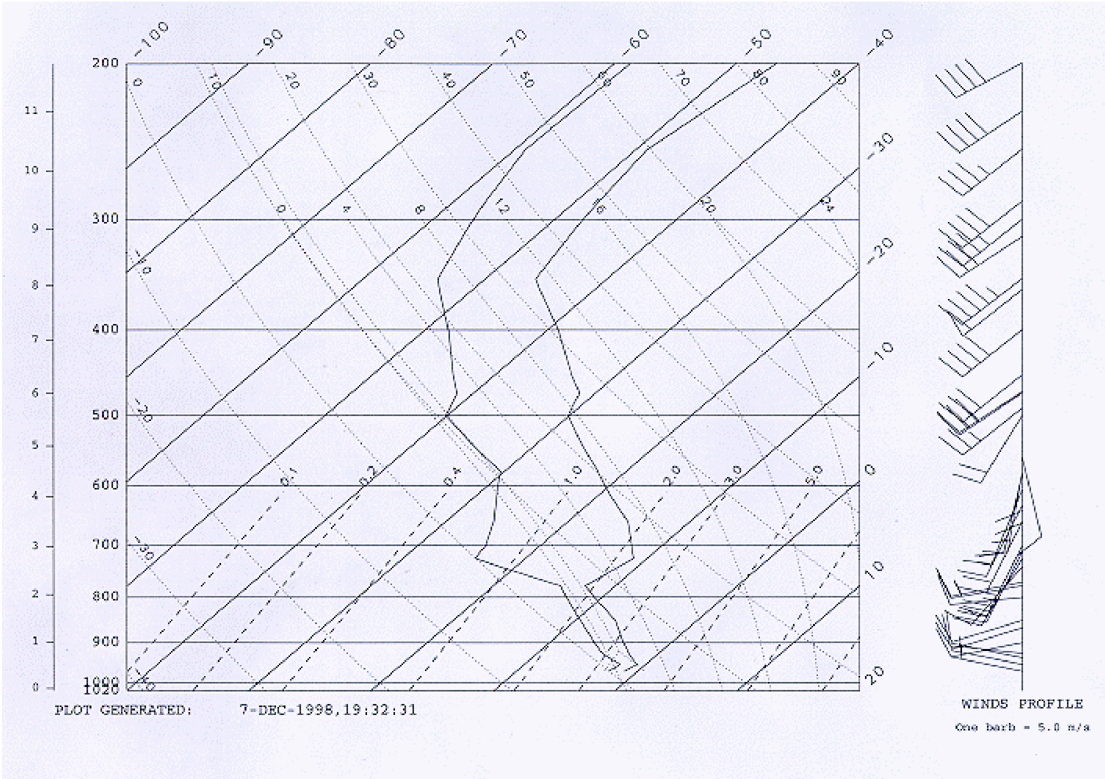


Figure 5 – Balloon-borne soundings from Detroit at c) 980302, 1200 and d) 980303, 0000 UTC.



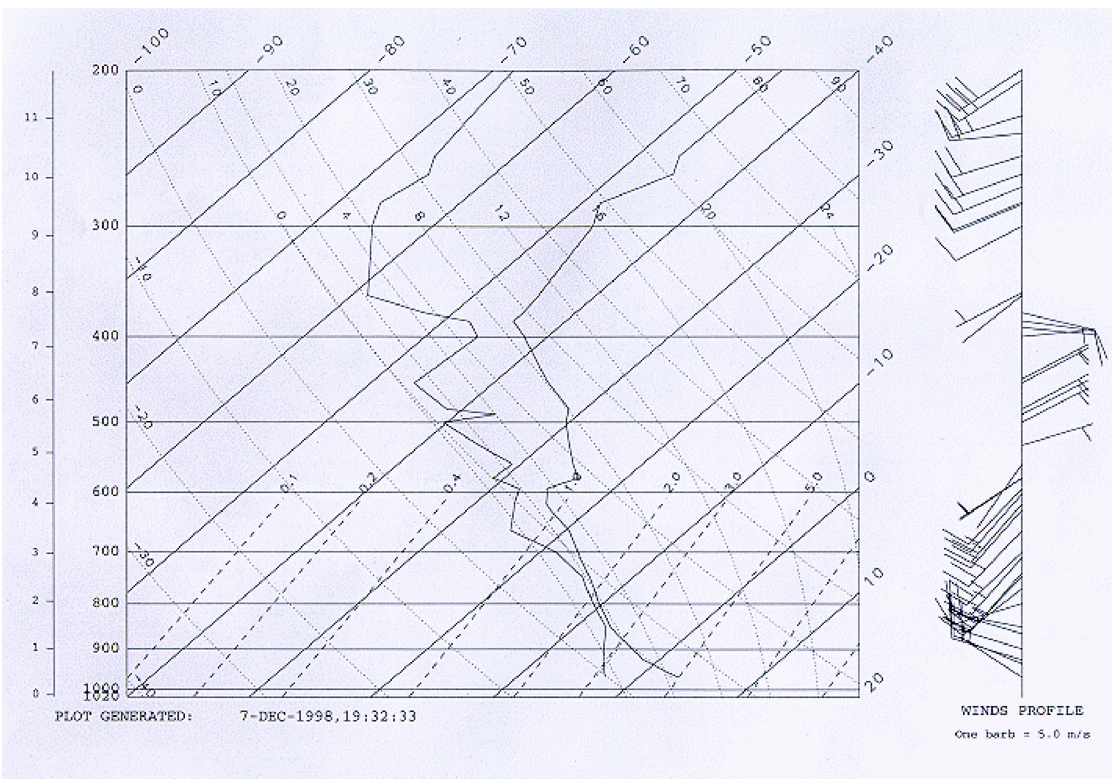
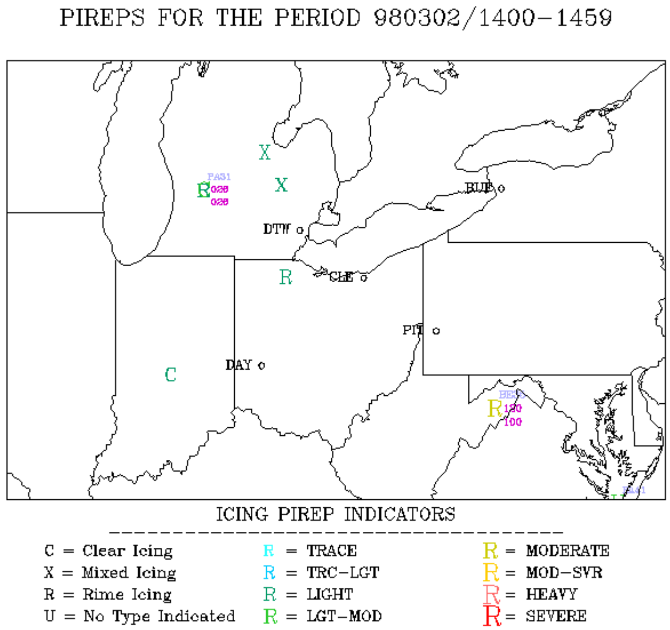


Figure 5 – Balloon-borne soundings from Wilmington at e) 980302, 1200 and f) 980303, 0000 UTC.



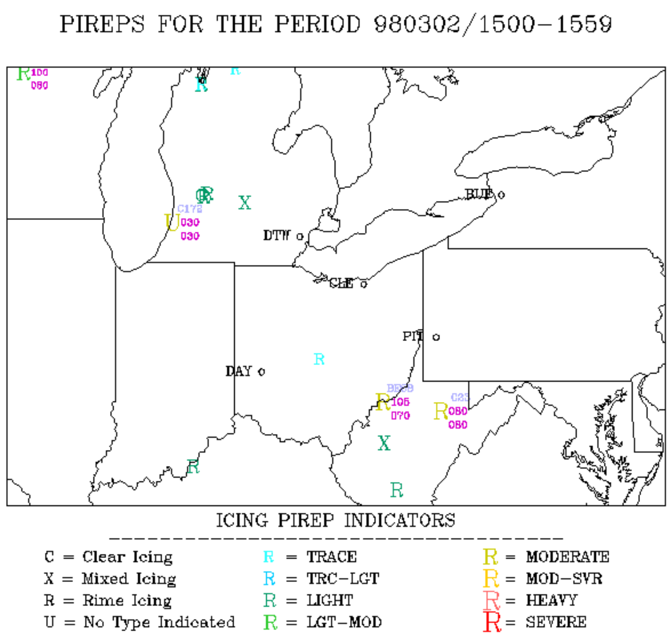
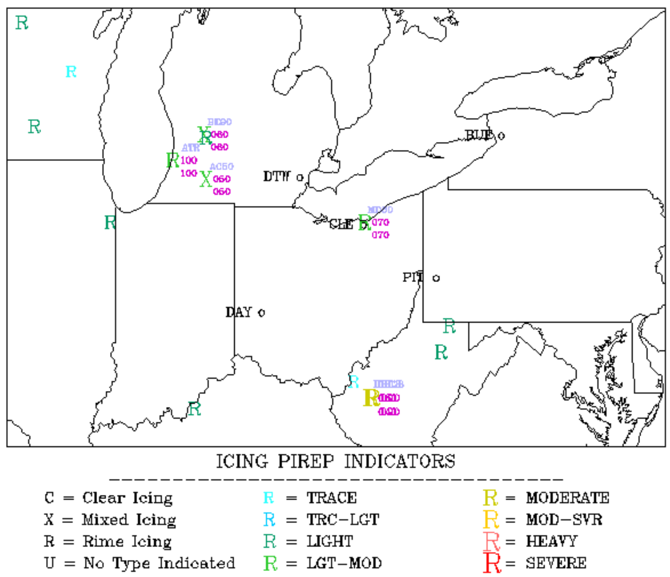


Figure 6 – Pilot reports of icing for 980302, a) 1400-1459 and b) 1500-1559 UTC.

PIREPS FOR THE PERIOD 980302/1600-1659



PIREPS FOR THE PERIOD 980302/1700-1759

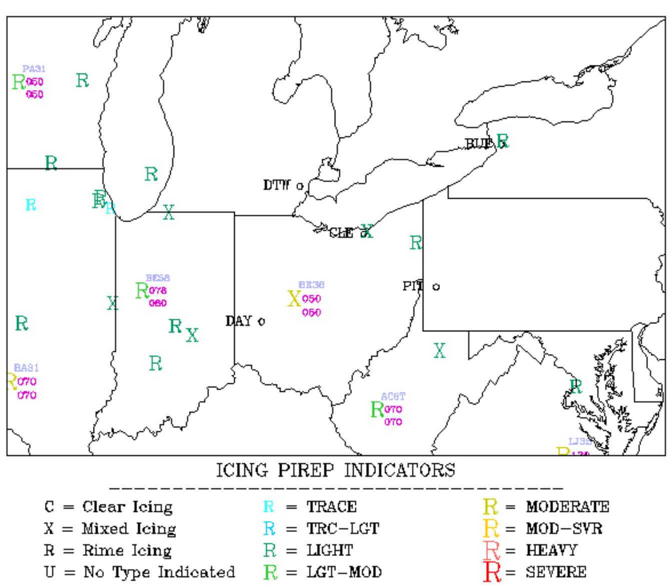
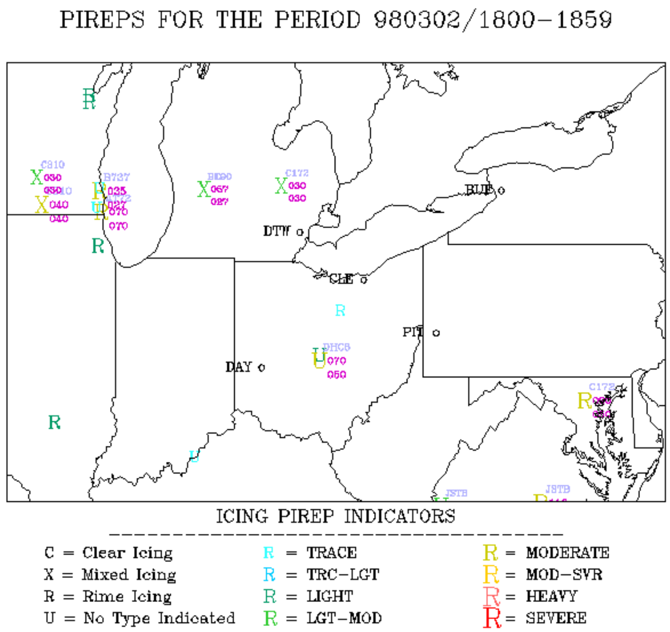


Figure 6 – Pilot reports of icing for 980302, c) 1600-1659 and d) 1700-1759 UTC.



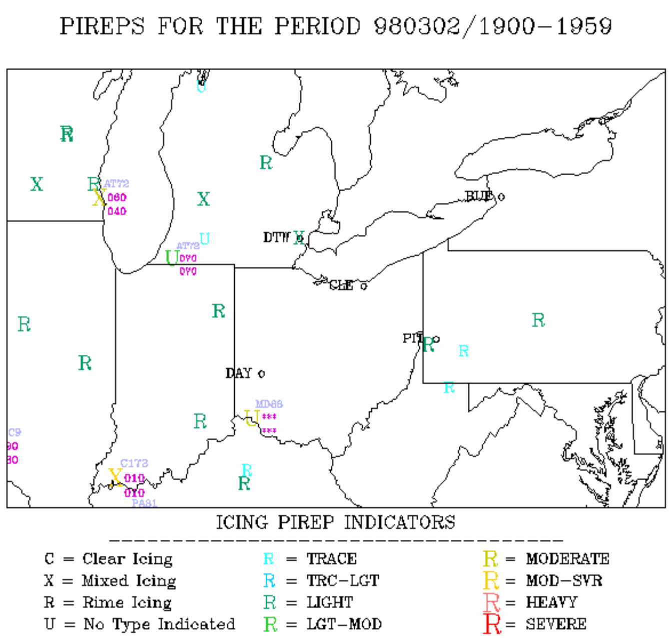


Figure 6 – Pilot reports of icing for 980302, e) 1800-1859 and f) 1900-1959 UTC.

March 5, 1998

Flight #1—Over Toledo, OH, Detroit, MI, and Selfridge AFB from 1533 to 1656 UTC.
Flight #2—Over Flint and Saginaw, MI, from 1823 to 1951 UTC.
Flight #3—Over Saginaw and Flint, MI, Selfridge AFB, and Lake Erie from 2109 to 2230 UTC.

Brief overview

Three flights were made into small-droplets, mixed conditions, and snow. During the first flight, light snow was observed during climbout from Cleveland through two cloud decks at 2500' and between 6000' and 6500'. The higher cloud deck had a CTT of –13C, and LWC up to 0.05. These same clouds contained fewer crystals and higher LWC (0.25) over Lake Erie. Cloud top temperatures were slightly warmer near Toledo (-12C) and the cloud deck roughly extended from 5000' to 6000'. Another deck had tops near 4800' there, and LWC up to 0.5. En-route to Selfridge at altitudes of 3800' to 4800', only a little LWC (< 0.1) and some ice crystals were found.

During the second flight, layered clouds that contained ragged LWC up to 0.5 were found near Flint between 6000' and 6500'. CTTs in this area were –12C to –13C. Lower water contents (0-0.25) and more ice crystals and mixed conditions were present over Saginaw. During flight number three, the clouds continued to vary between all-water and mixed-phase between Saginaw and about half way across Lake Erie. LWC was up to 0.6 in some all-water, small-droplet clouds just to the north of Selfridge. Cloud top heights remained near 6600'. LWC decreased as the aircraft went south toward Lake Erie between 6000' and 6500'. The aircraft broke into clear skies about half way across Lake Erie.

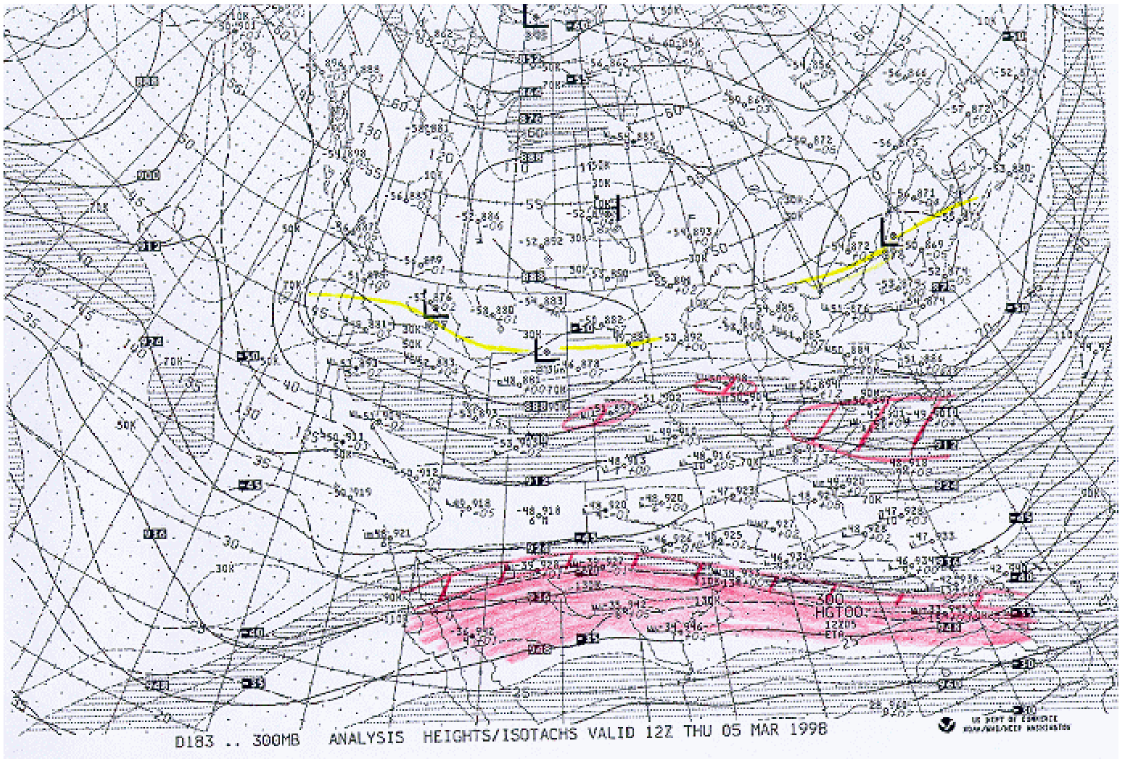
Relevant weather features

At 1200 UTC, a weak 500 mb low was centered over northern New York state (Fig. 1). A small area of moisture surrounded the low, but dry conditions covered the forecast area. At 700 mb, only a couple of troughs remained, with one over central Michigan. Saturated air existed along this portion of the trough, as well as to the east. Temperatures in the moist areas were near -15C. Dry conditions and no strong temperature advection were present over Ohio. Moisture was widespread, and very little of the trough remained at 850 mb. A pocket of cool air sat along the southern Michigan border. Northerly flow through that pool caused cold and warm advection to its south and north, respectively. By 0000 UTC, some high-level moisture was evident at 500 mb from North Dakota to Indiana and southwestern Ohio, while the rest of the forecast area was dry at this level (Fig. 2). Things were dry across the region at 700 mb, but quite moist at 850 mb. The 850 mb cool pocket had been wiped out, and cold advection was present to the east of Detroit.

Surface charts for the period show that winds were generally from the north and northeast (Fig. 3). This was caused by a mild pressure gradient between a 1030 mb high to the north of Lake Superior and a 1000 mb low off the Massachusetts coast. The winds came across the great Lakes, providing some opportunity for lake enhancement. The 1200 UTC Alpena MI sounding (Fig. 4) indicated that lake-

induced convection was unlikely over northern Michigan, as stable lapse rates were present at 900 mb. Lapse rates became more unstable by 0000 UTC, but little moisture was available. Clouds that existed over the area had thinned markedly. Detroit had a slightly more unstable profile at 1200 UTC, and a cap at 830 mb. Warm clouds that were present there also appeared to thin out by 0000 UTC. The same was true at Wilmington.

Satellite imagery (Fig. 5) showed that several wide breaks were present in what appeared to be solid, widespread cloudiness on the 850 mb charts. Warm (CTTs near -10C) and slightly cooler (CTTs near -15C) cloud tops were evident over southwestern Ohio, and near the Michigan-Ohio border, respectively. The Michigan and northern Ohio cloud tops warmed slightly during the day. Some breaks moved through the area, especially over Lake Erie, but otherwise this cloud deck held together through 2215 UTC. Radar mosaic data and surface observations (Figs. 2, 6) indicated that widespread light snow fell across western Pennsylvania, western New York, northeastern Ohio, southeastern Ontario, and just to the south of Lake Huron through 2000 UTC. Occasional patches of light snow popped up elsewhere (including over Saginaw), but were short-lived. PIREPs of moderate severity rime and mixed icing were common across the region (Fig. 7). Most indicated that the icing was at altitudes between 4000’ and 8000', but one PIREP from Saginaw mentioned icing down to 2200'.



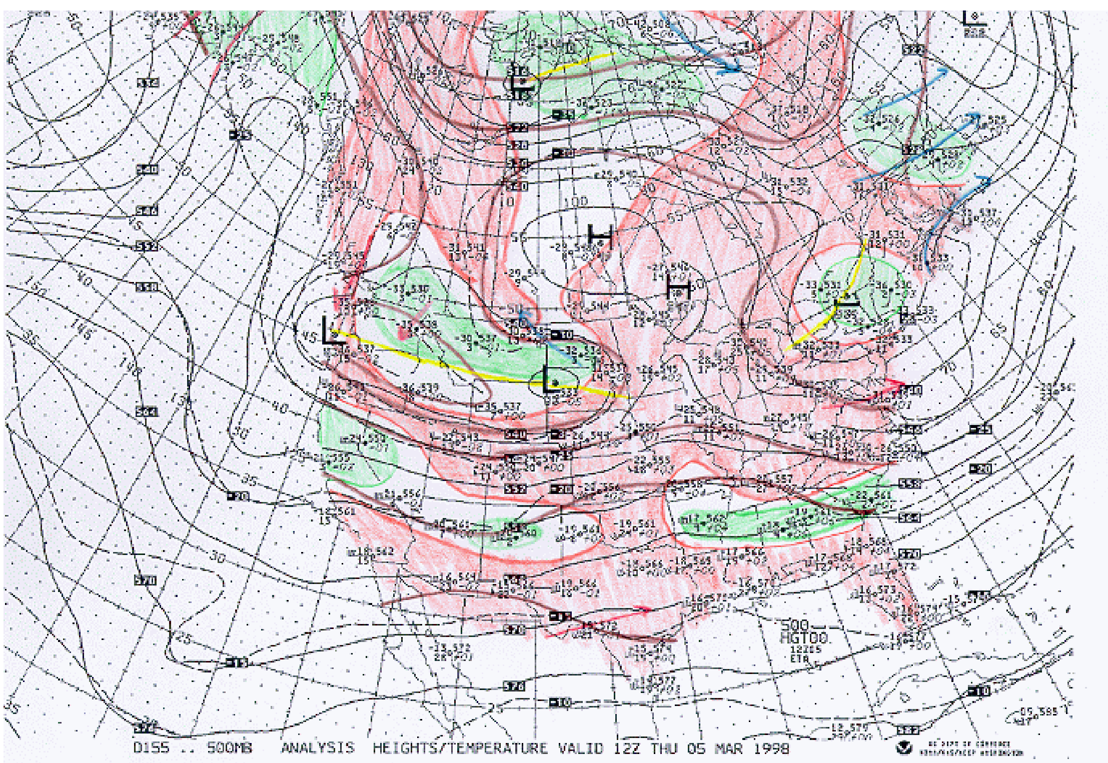
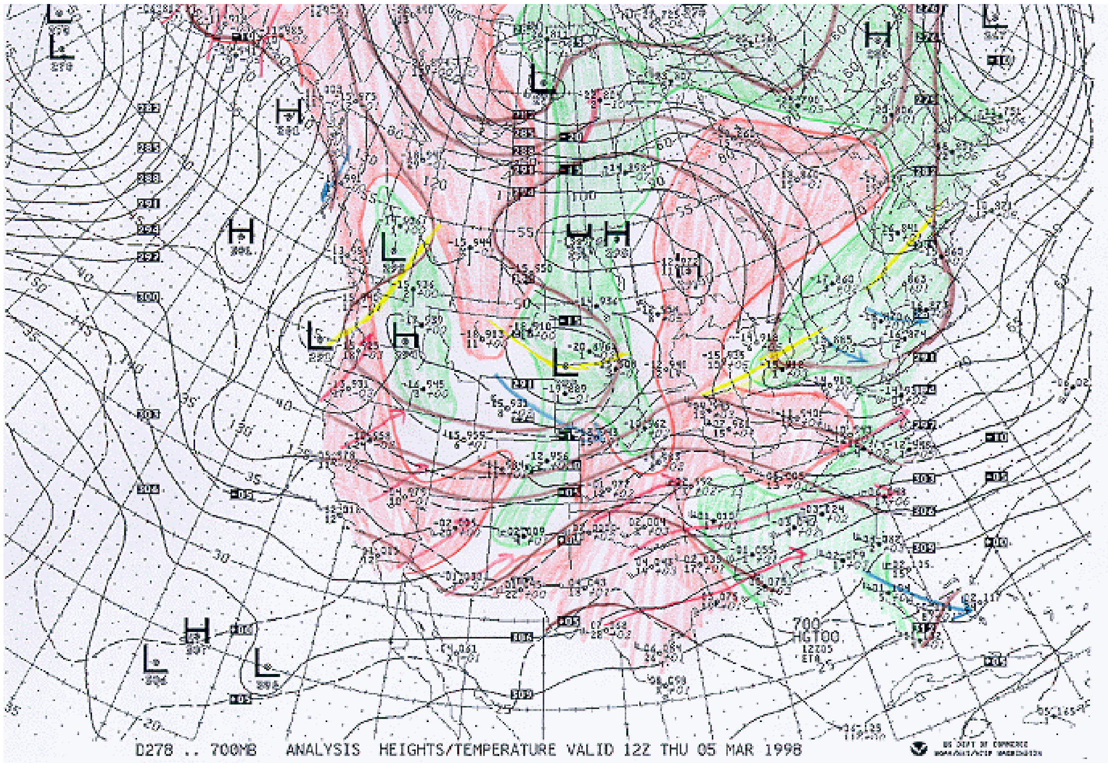


Figure 1 – Upper-air charts for 980305, 1200 UTC at a) 300 and b) 500 mb.



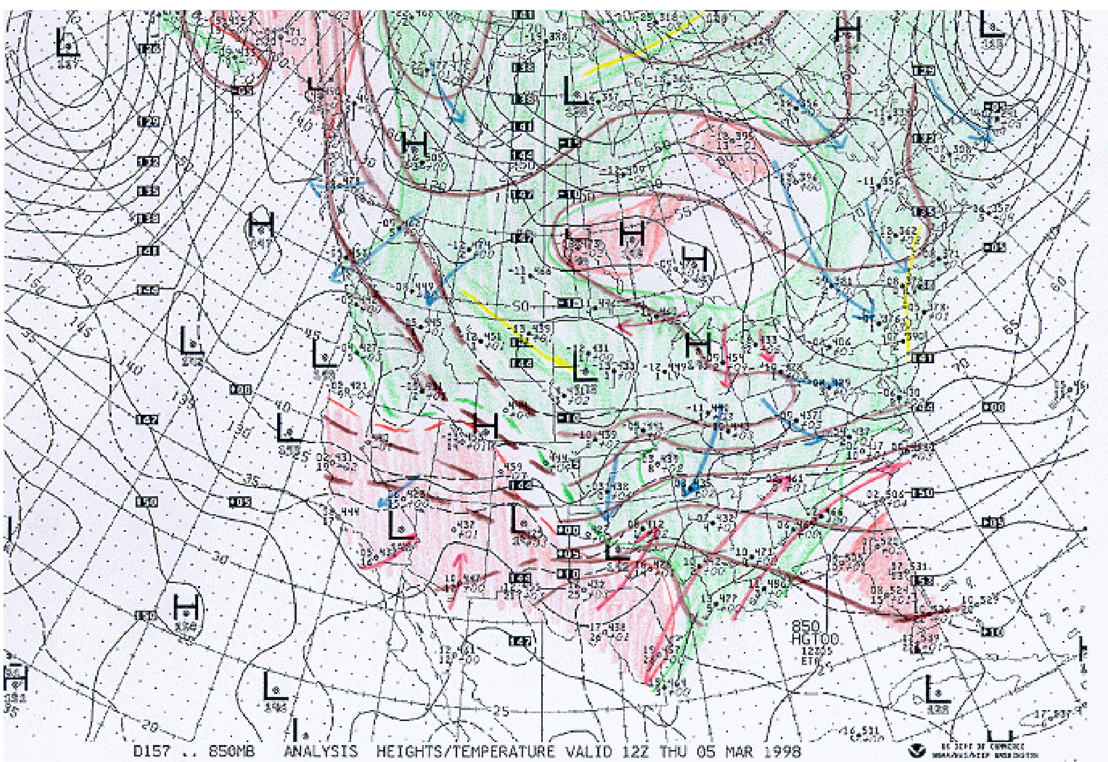
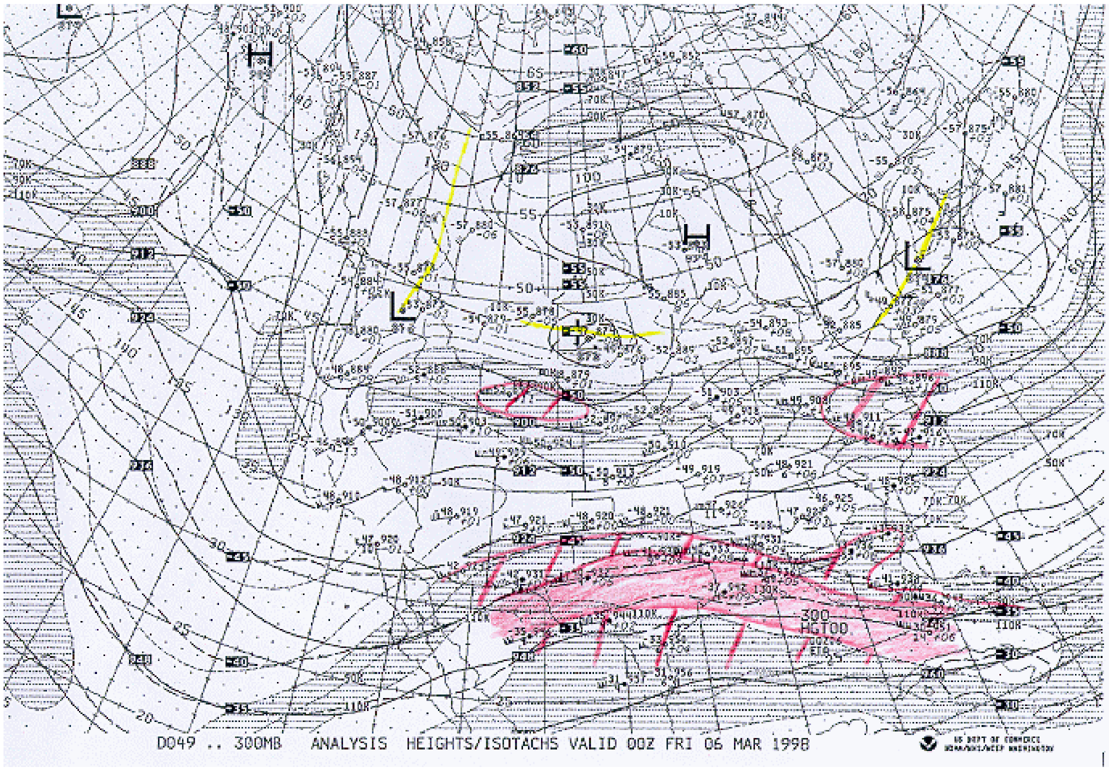


Figure 1 – Upper-air charts for 980305, 1200 UTC at c) 700 and d) 850 mb.



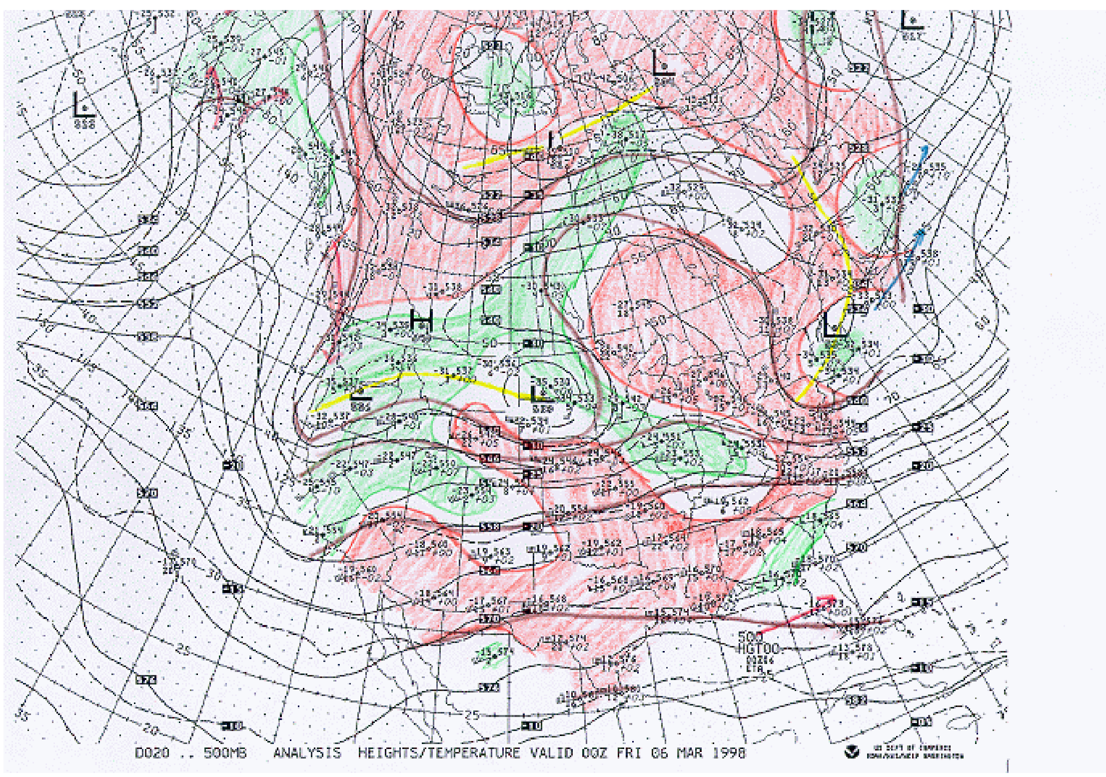
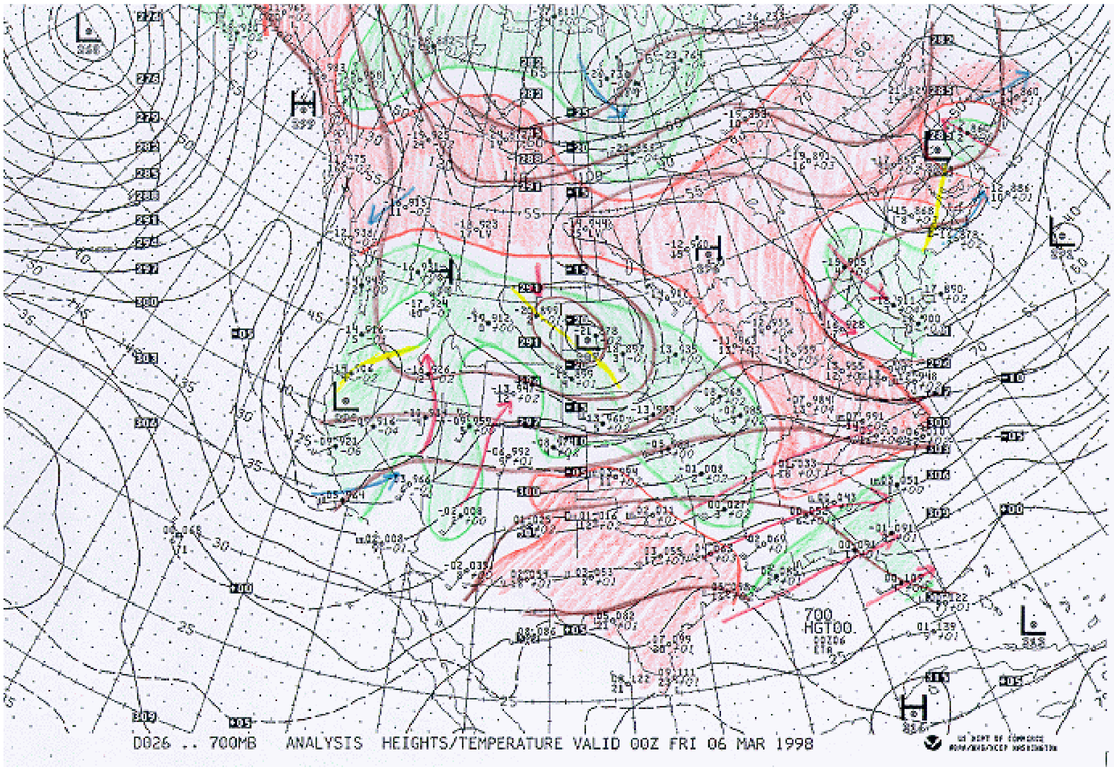


Figure 2 – Upper-air charts for 980306, 0000 UTC at a) 300 and b) 500 mb.



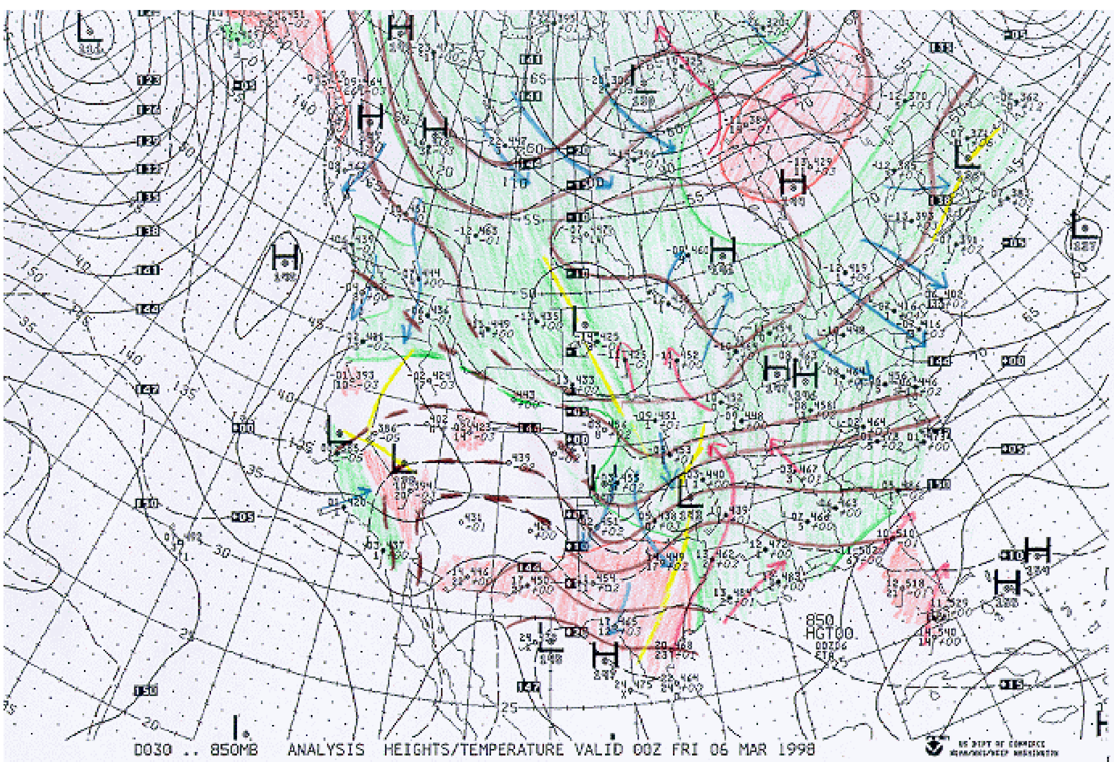
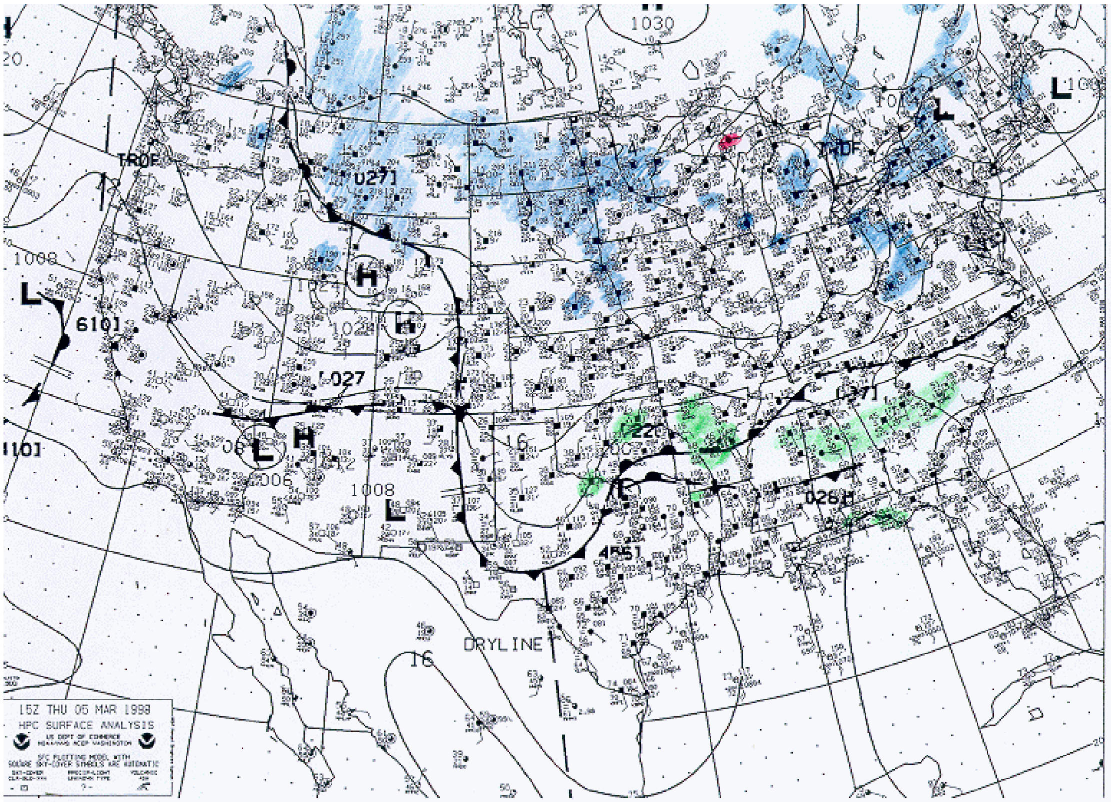


Figure 2 – Upper-air charts for 980306, 0000 UTC at c) 700 and d) 850 mb.



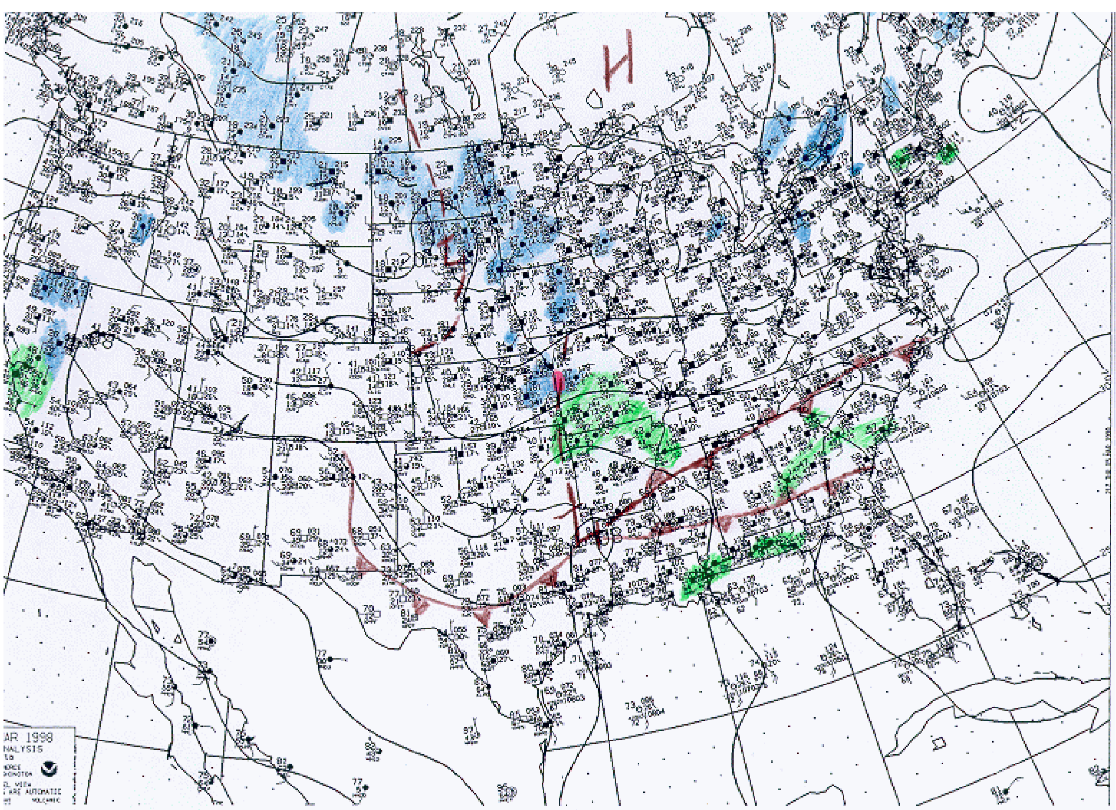


Figure 3 – Surface charts for 980305, a) 1500 and b) 2100 UTC.

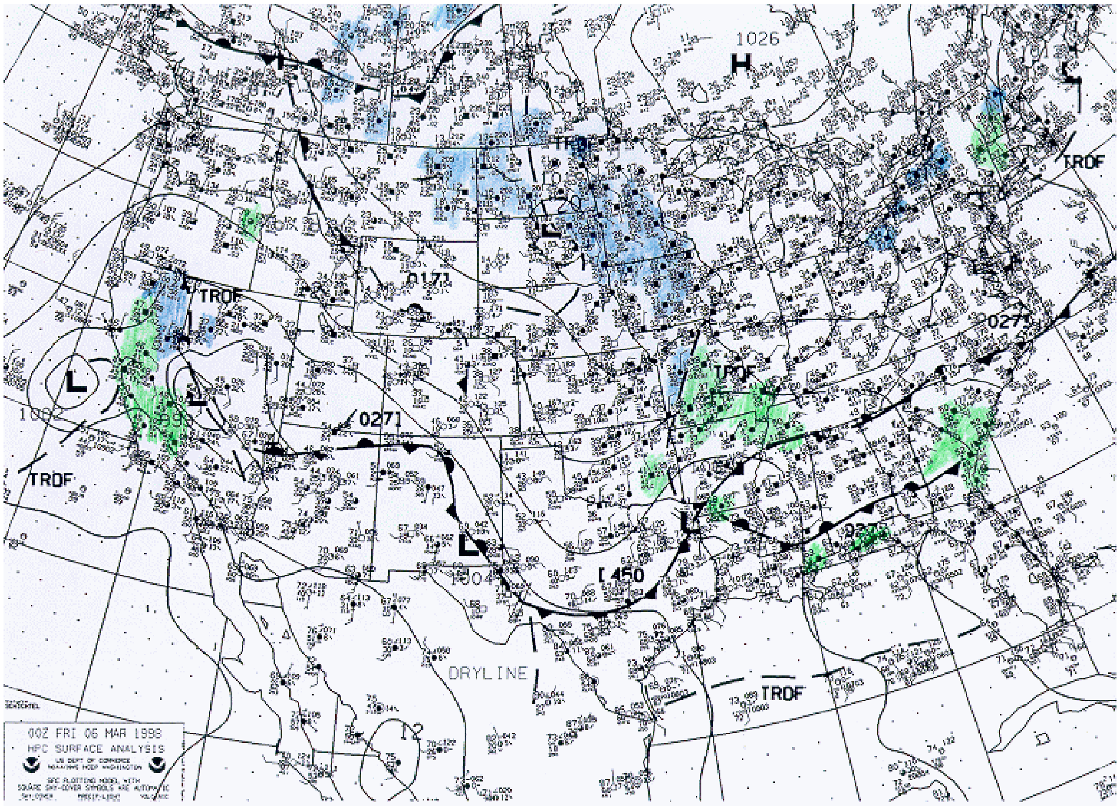
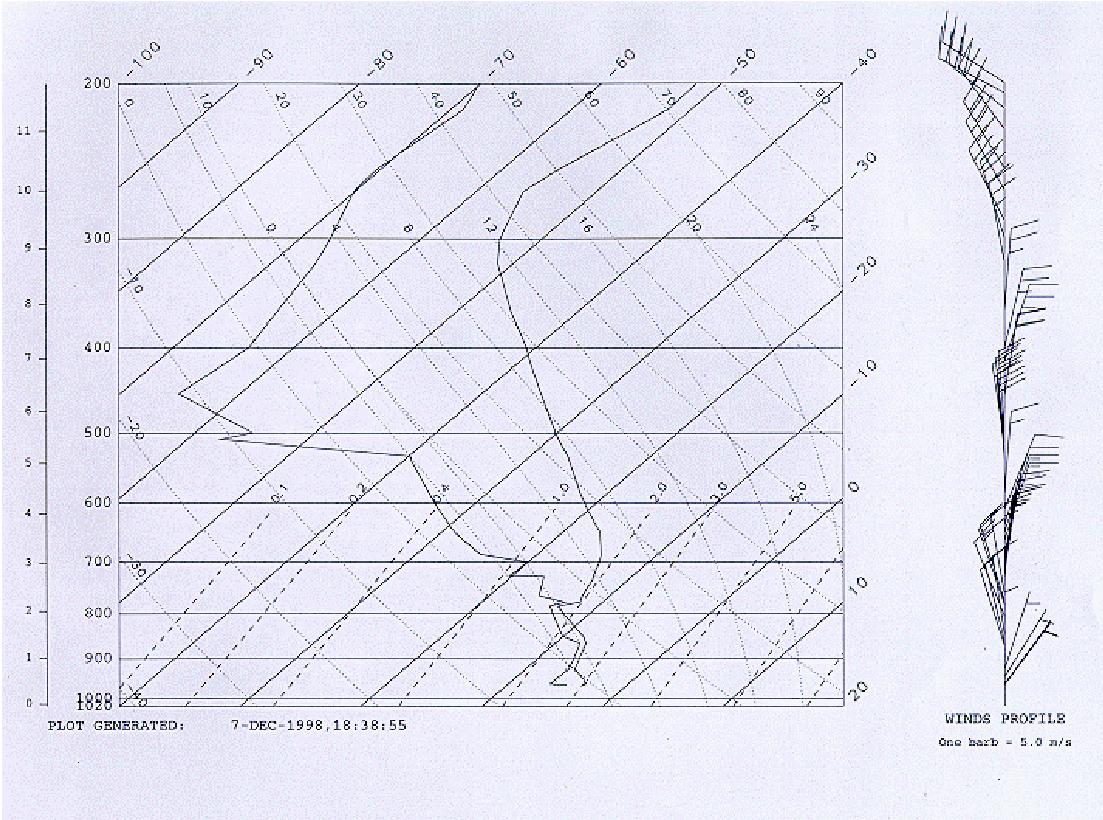


Figure 3 – Surface chart for 980306, c) 0000 UTC.



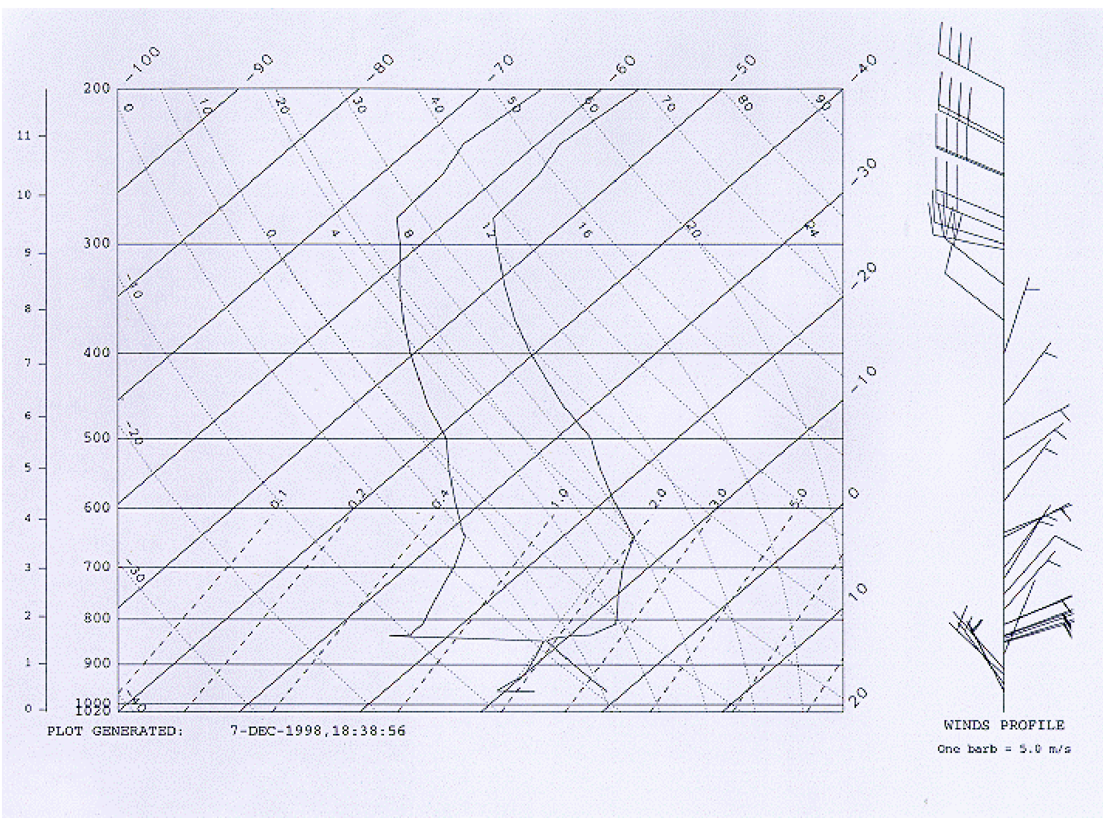
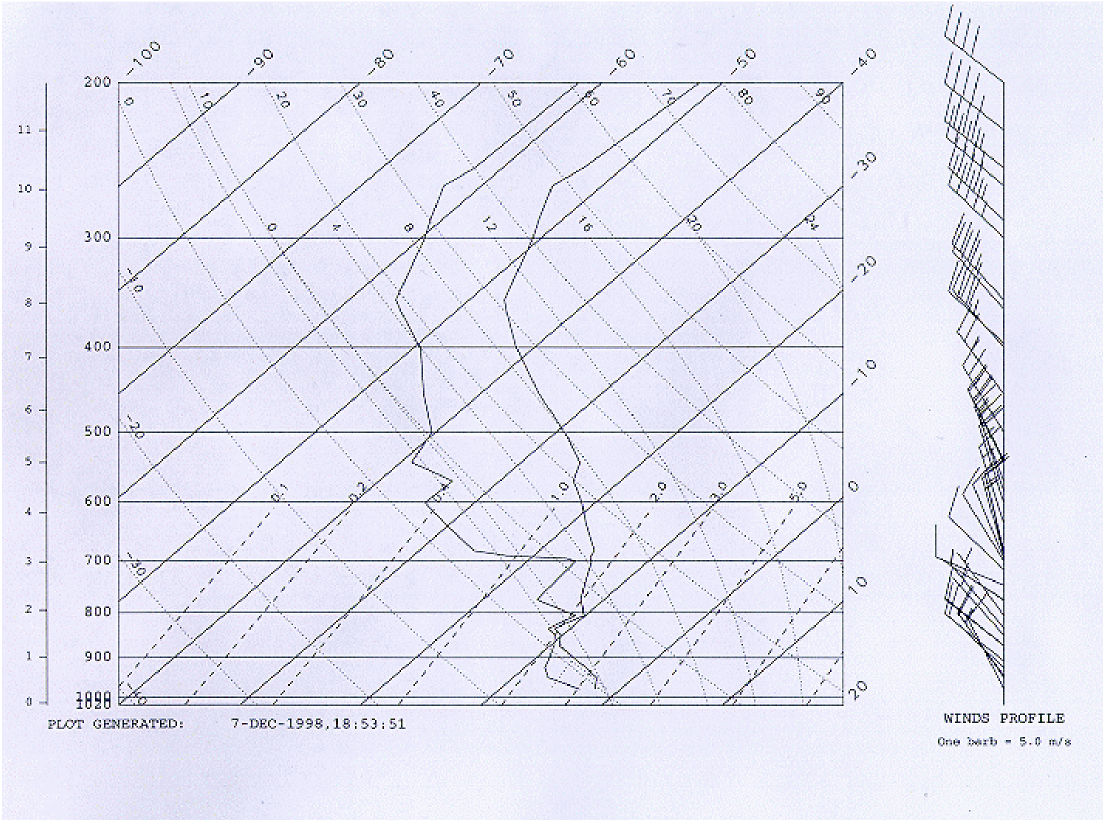


Figure 4 – Balloon-borne soundings from Alpena MI at a) 980305, 1200 and b) 980306, 0000 UTC.



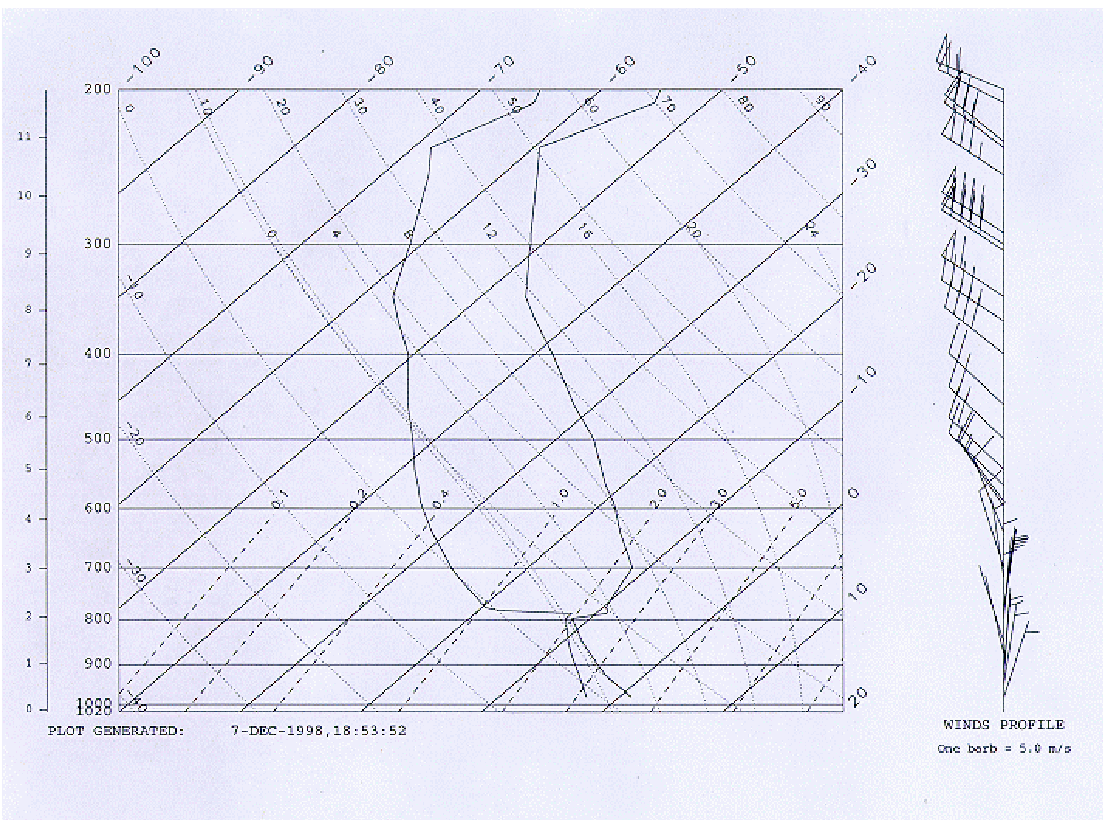
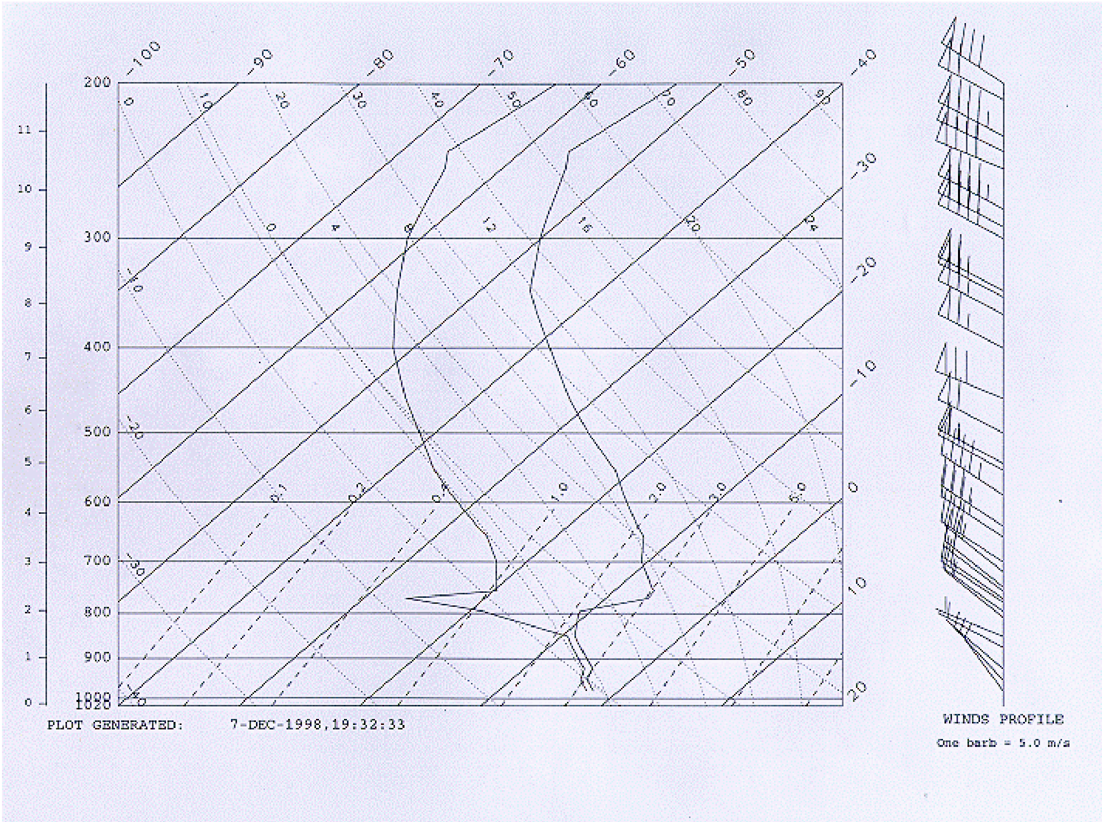


Figure 4 – Balloon-borne soundings from Detroit at c) 980305, 1200 and d) 980306, 0000 UTC.



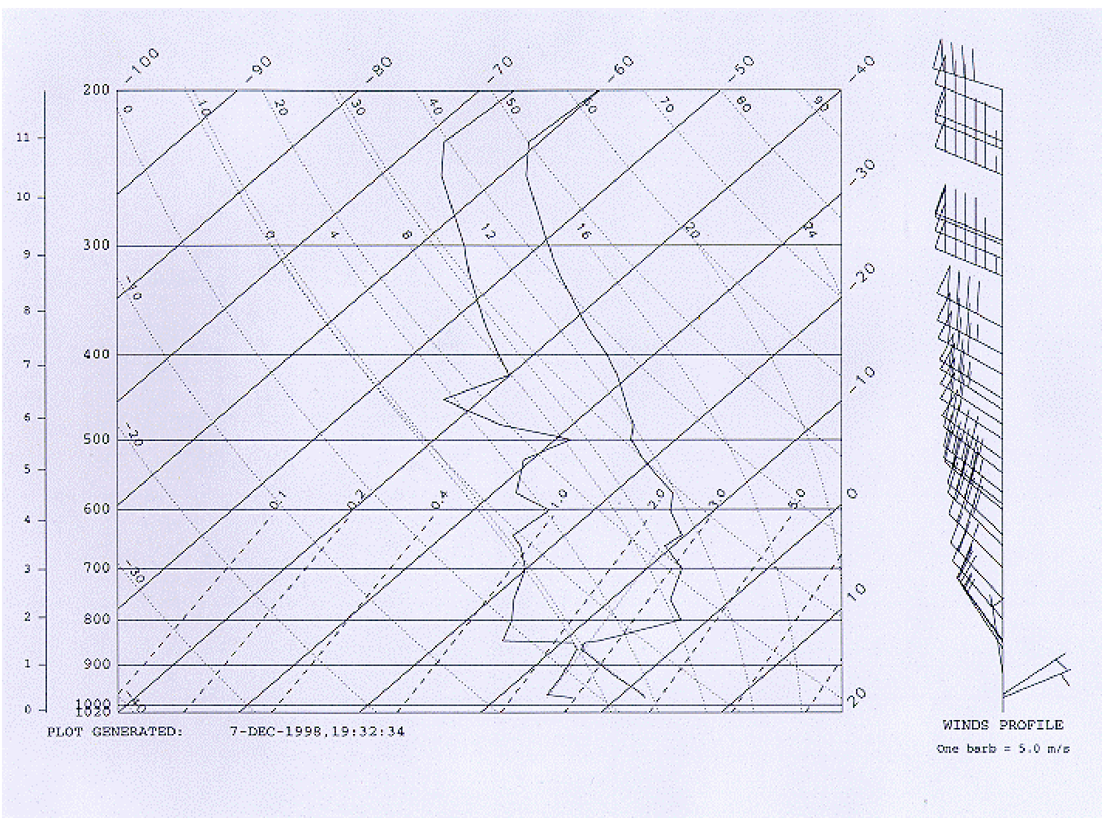
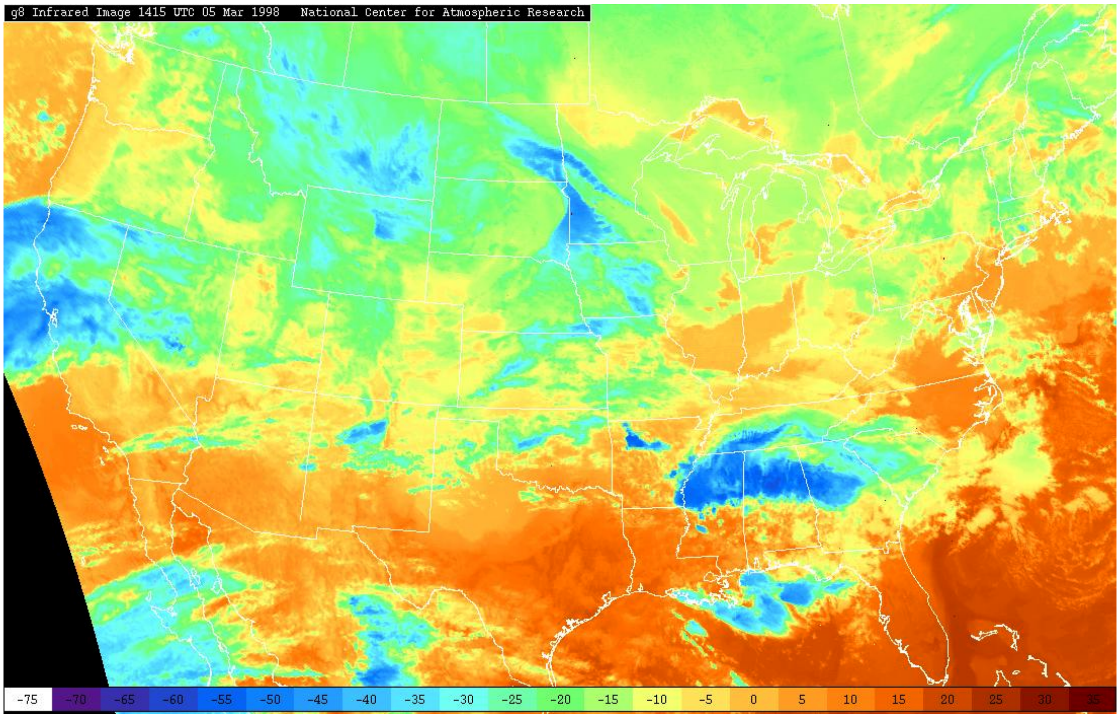


Figure 4 – Balloon-borne soundings from Wilmington at e) 980305, 1200 and f) 980306, 0000 UTC.



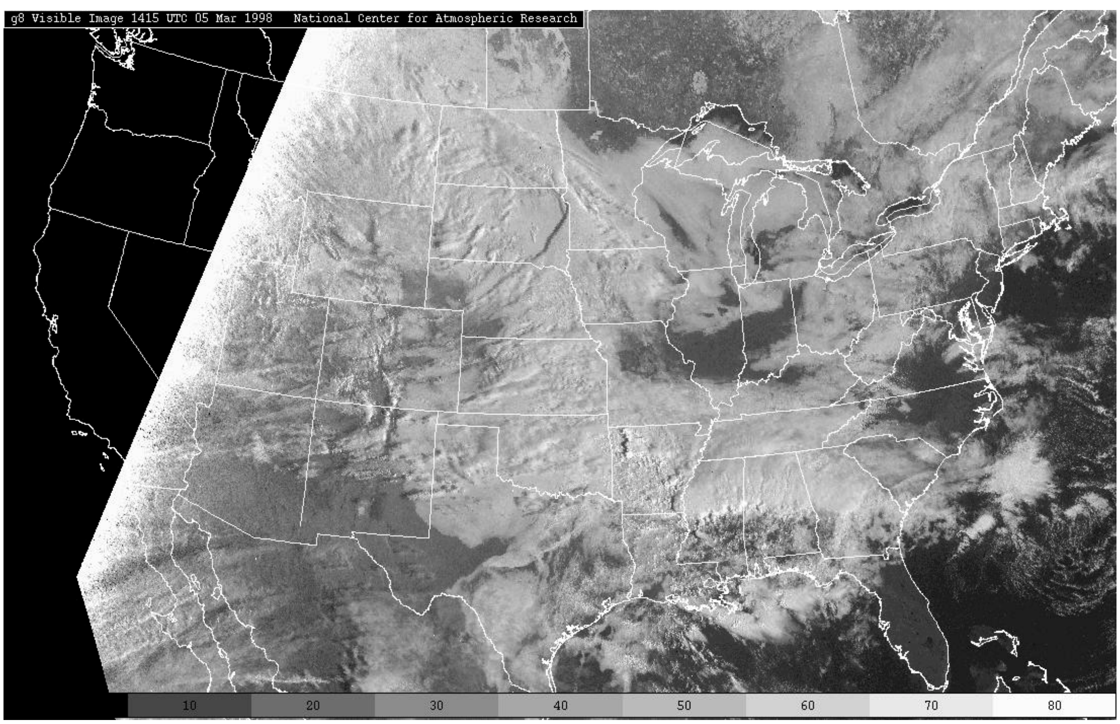
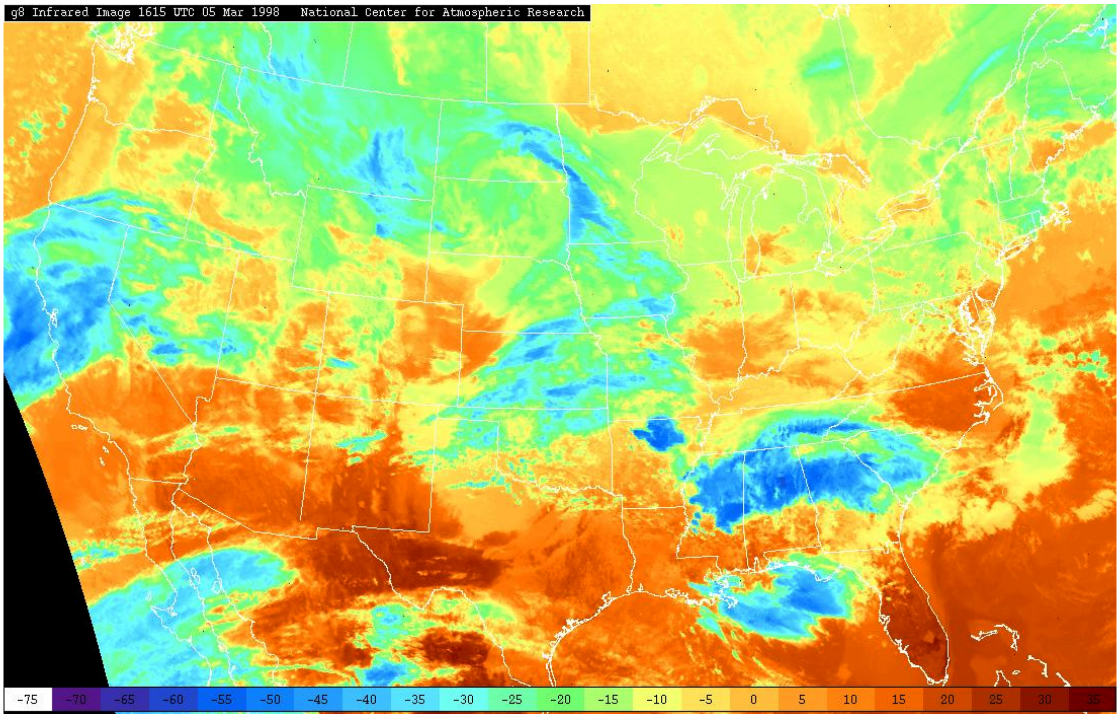


Figure 5 – GOES-8 a) infrared and b) visible satellite images for 980305, 1415 UTC.



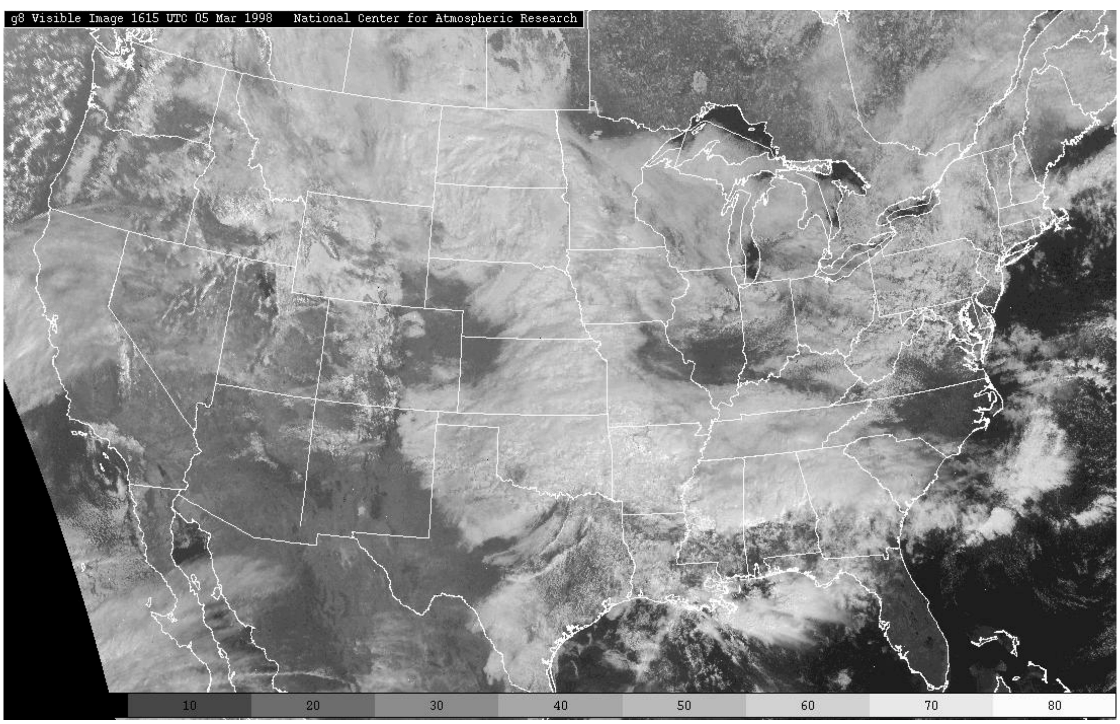
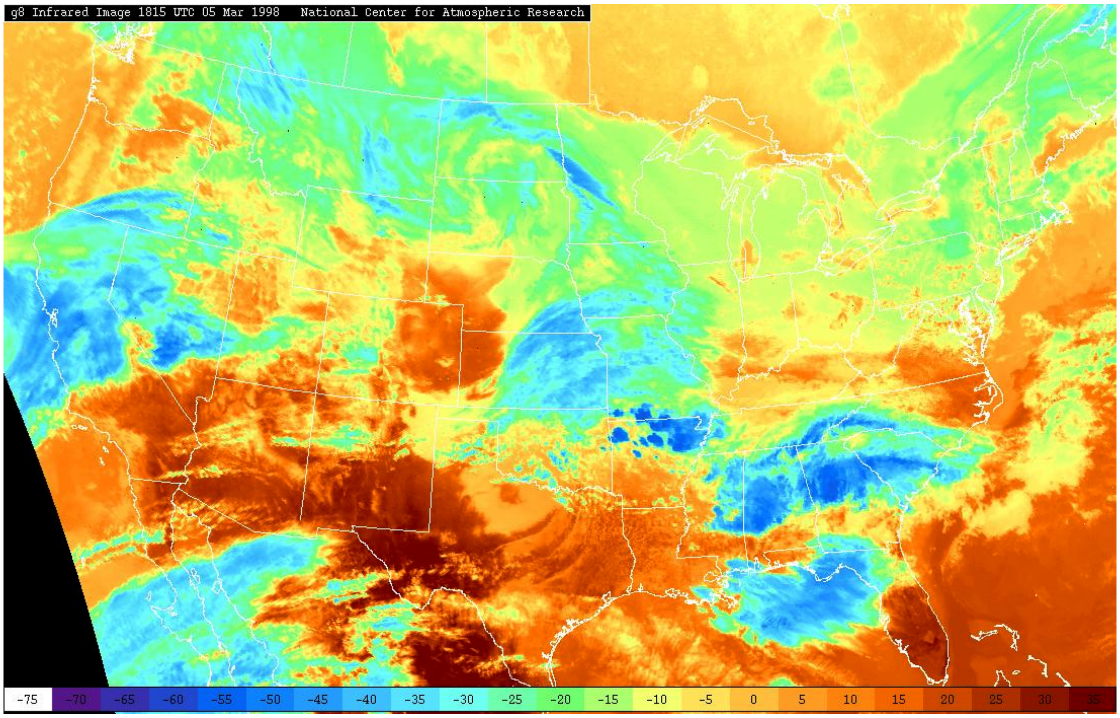


Figure 5 – GOES-8 c) infrared and d) visible satellite images for 980305, 1615 UTC.



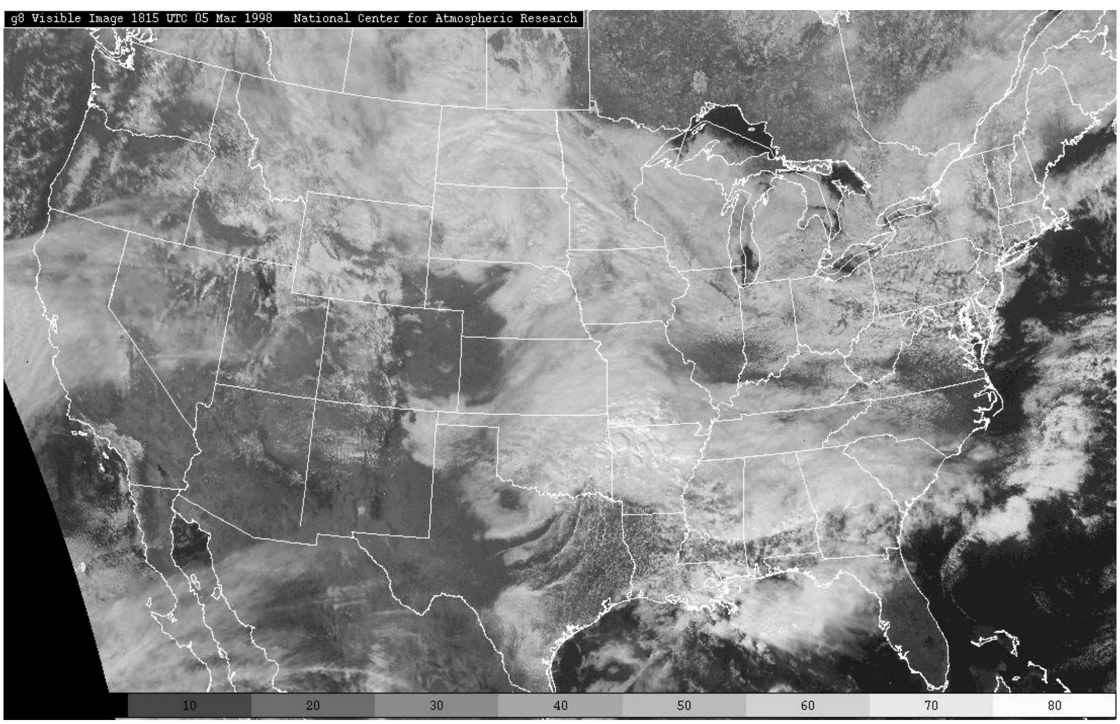
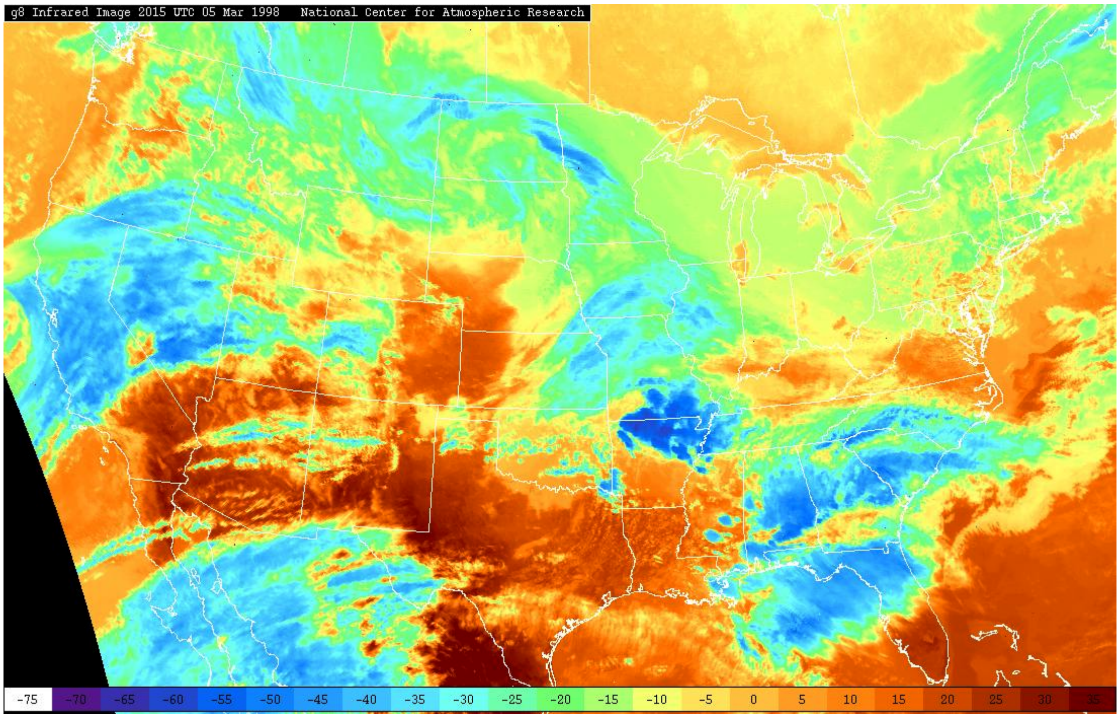


Figure 5 – GOES-8 e) infrared and f) visible satellite images for 980305, 1815 UTC.



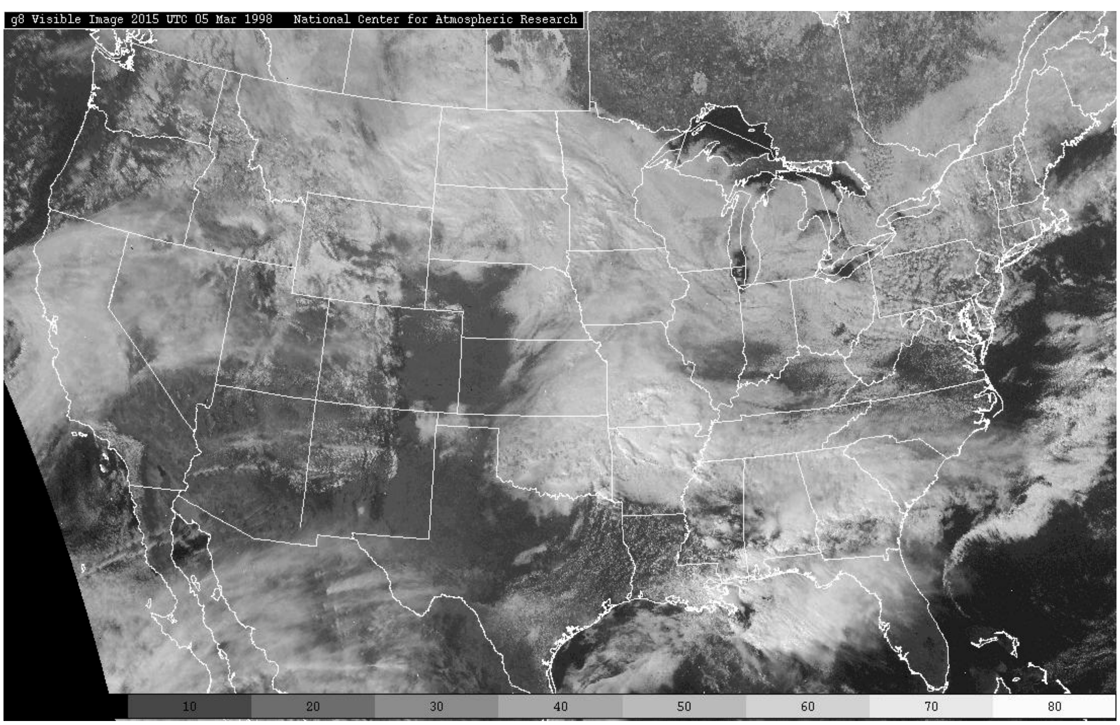
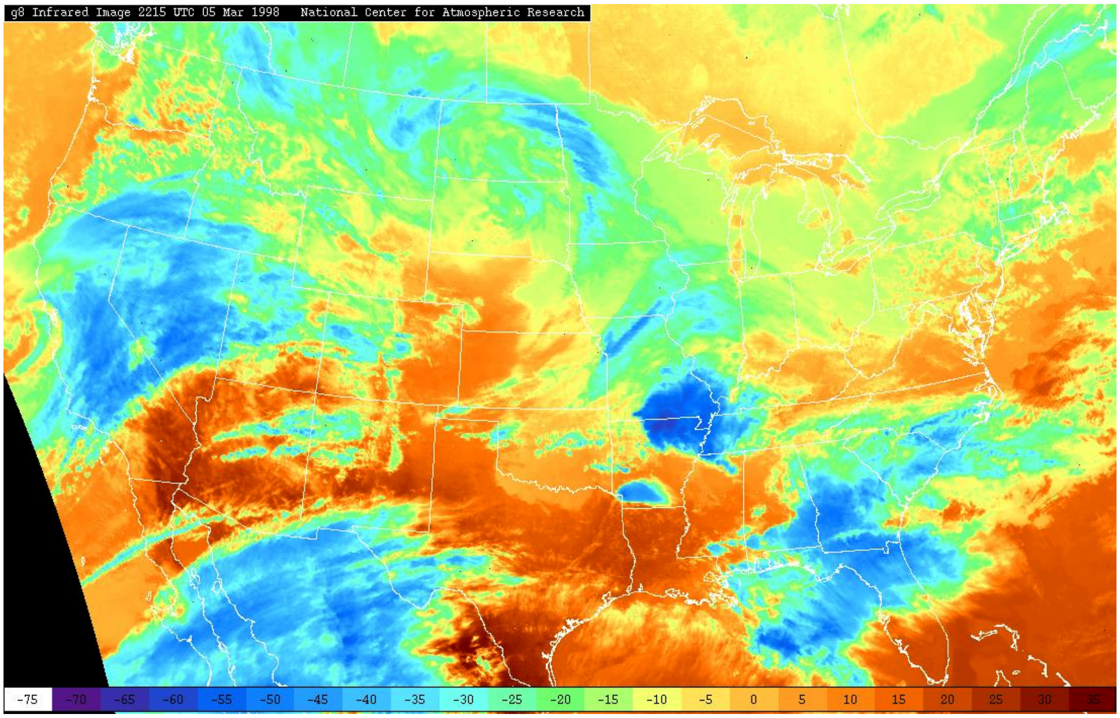


Figure 5 – GOES-8 g) infrared and h) visible satellite images for 980305, 2015 UTC.



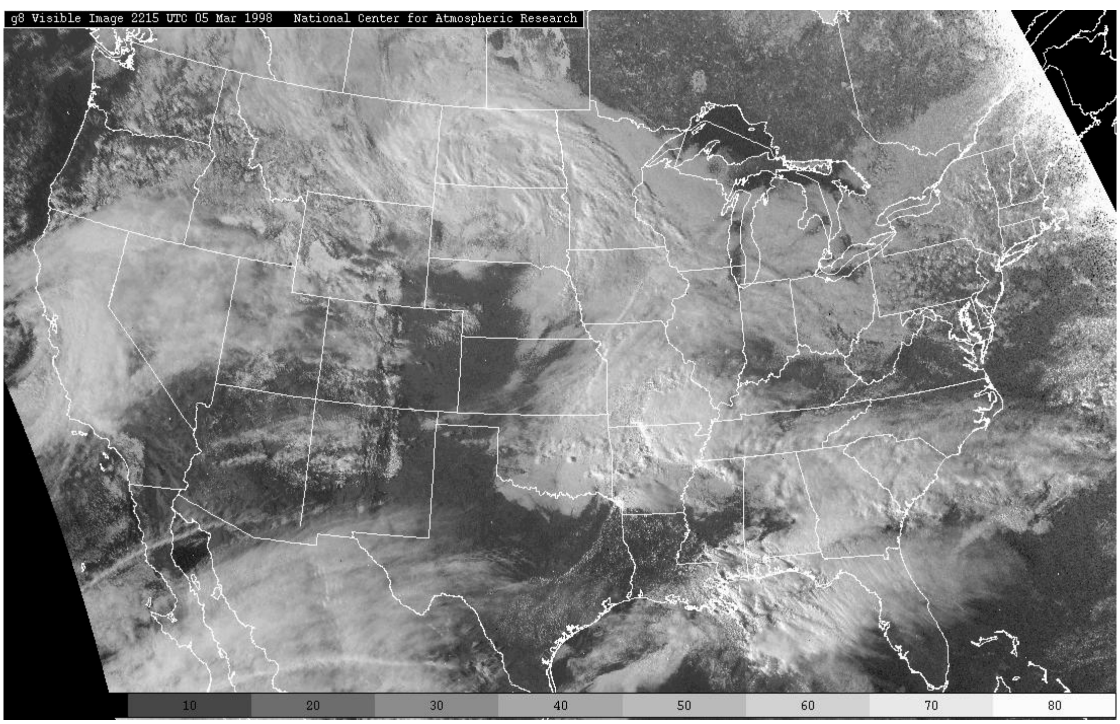
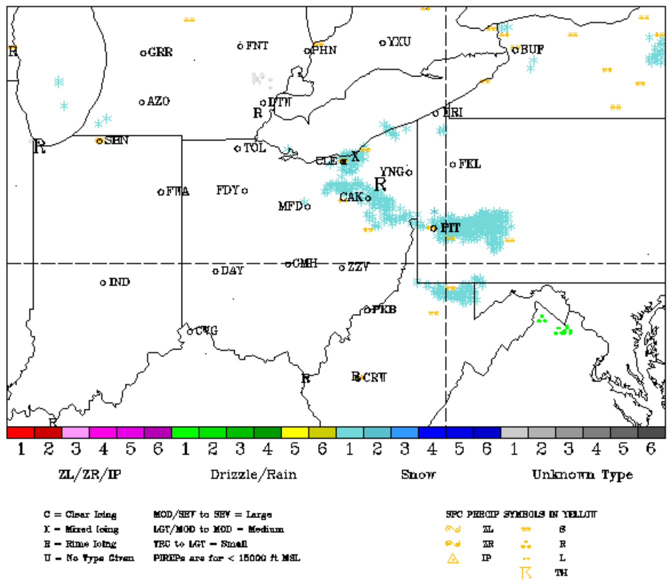


Figure 5 – GOES-8 i) infrared and j) visible satellite images for 980305, 2215 UTC.

RADAR DATA PLOT FOR 980305 AT 15 Z



RADAR DATA PLOT FOR 980305 AT 16 Z

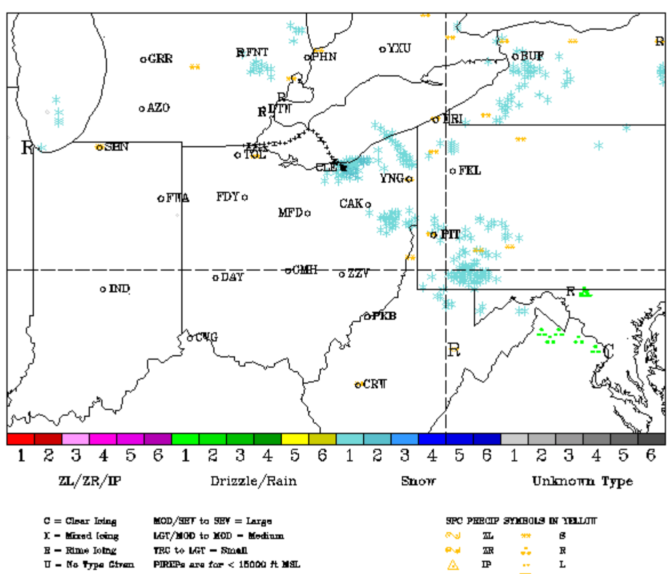
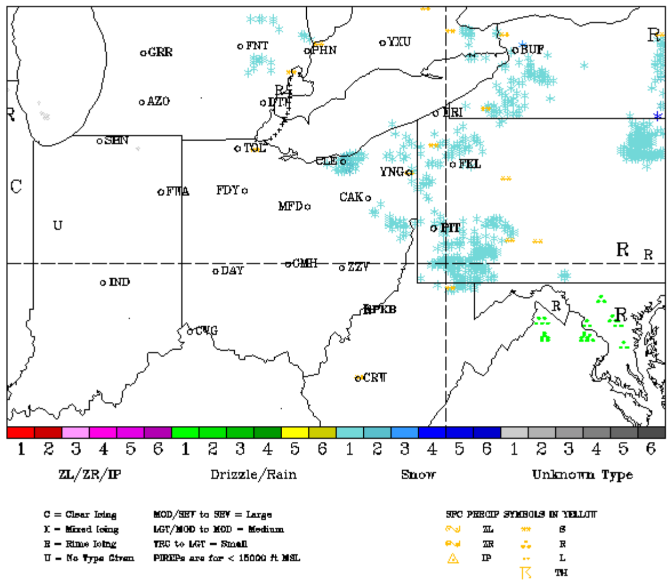


Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980305, a) 1500 and b) 1600 UTC.

RADAR DATA PLOT FOR 980305 AT 17 Z



RADAR DATA PLOT FOR 980305 AT 18 Z

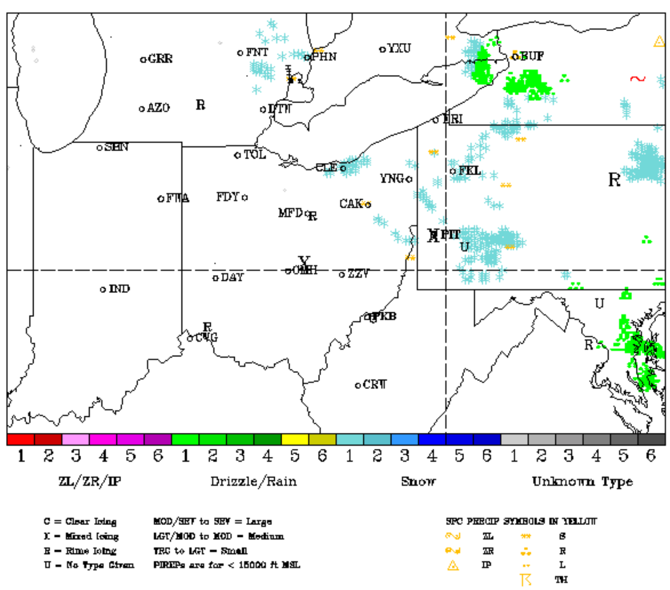
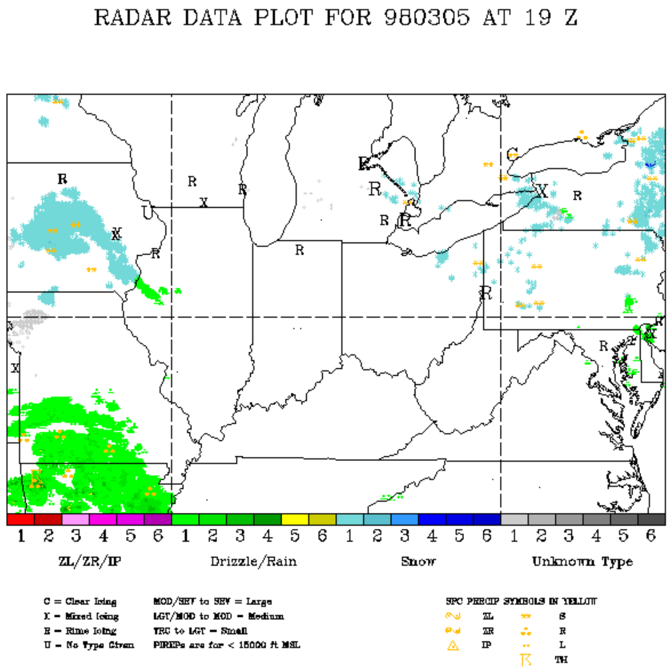


Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980305, c) 1700 and d) 1800 UTC.



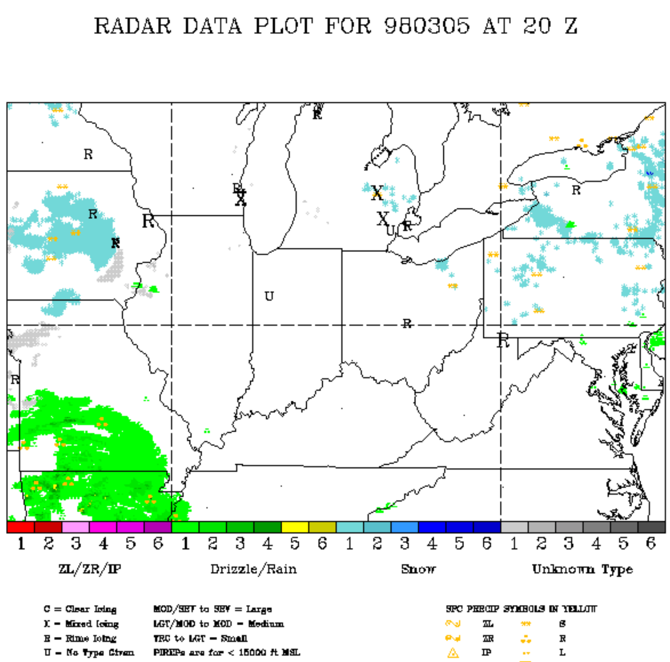
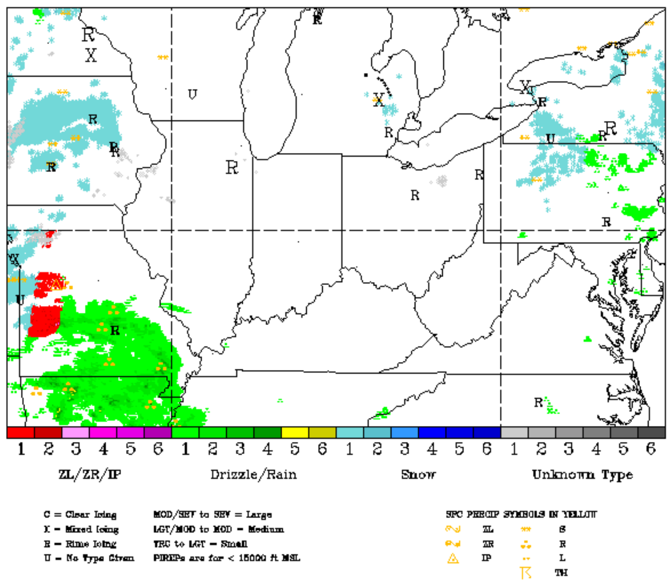


Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980305, e) 1900 and f) 2000 UTC.

RADAR DATA PLOT FOR 980305 AT 21 Z



RADAR DATA PLOT FOR 980305 AT 22 Z

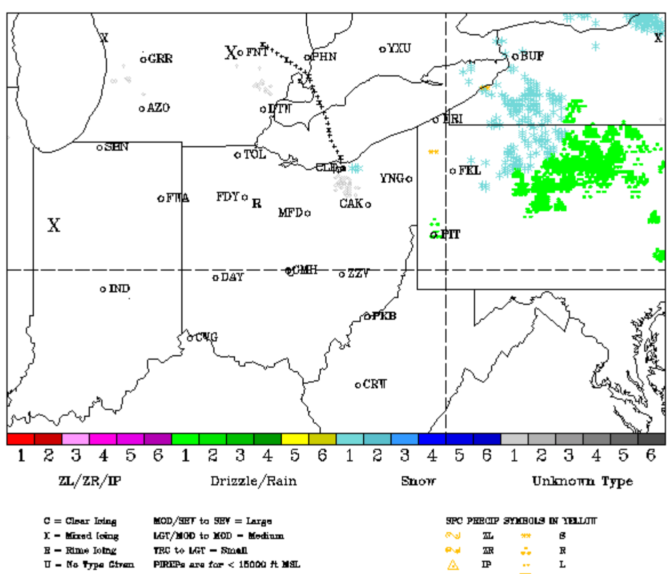
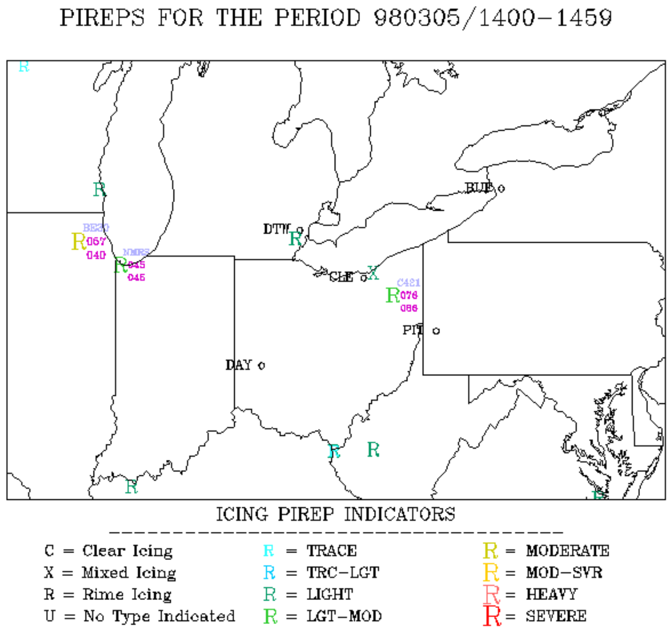


Figure 6 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980305, g) 2100 and h) 2200 UTC.



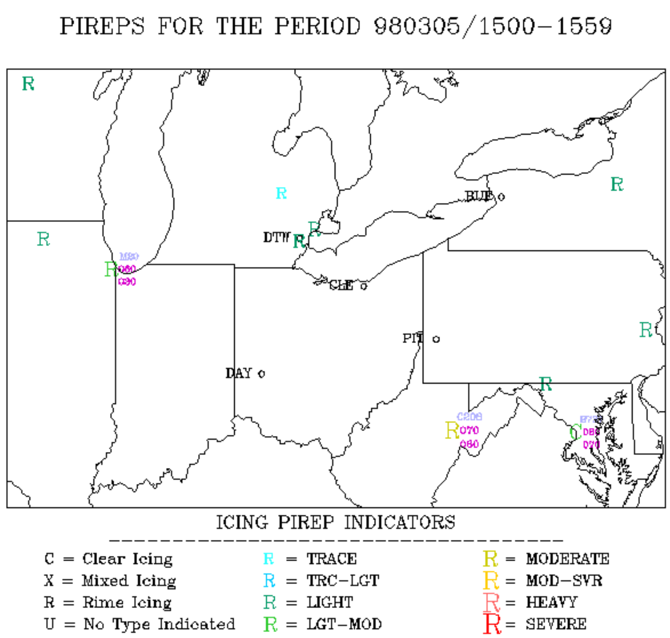


Figure 7 – Pilot reports of icing for 980305, a) 1400-1459 and b) 1500-1559 UTC.

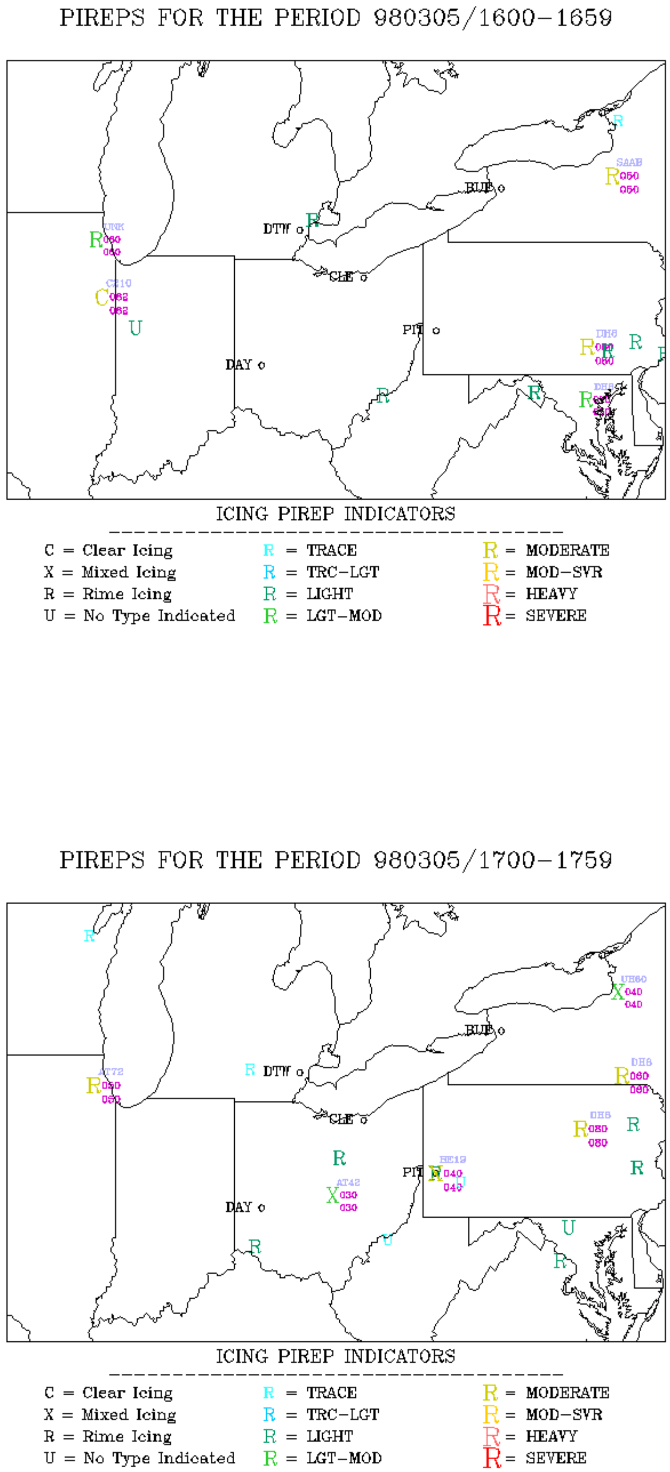
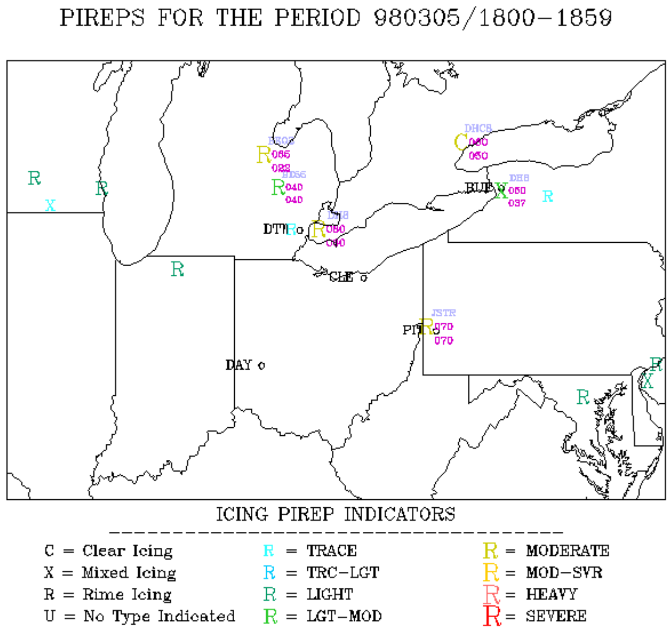


Figure 7 – Pilot reports of icing for 980305, c) 1600-1659 and d) 1700-1759 UTC.



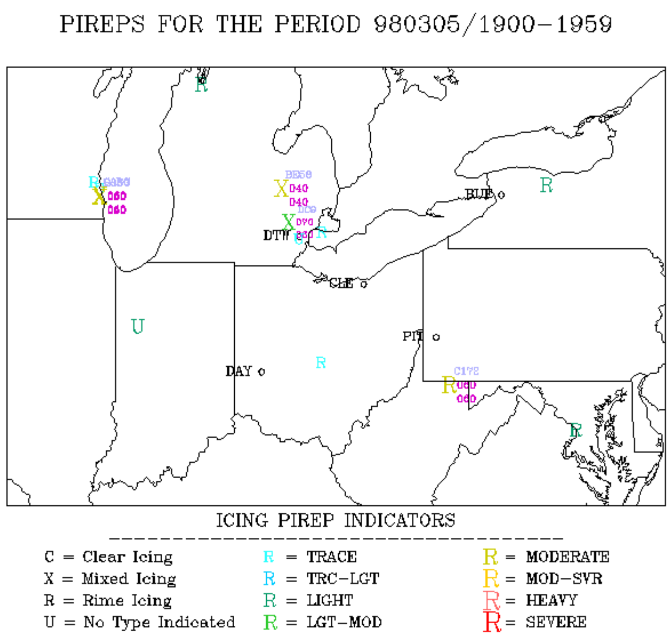
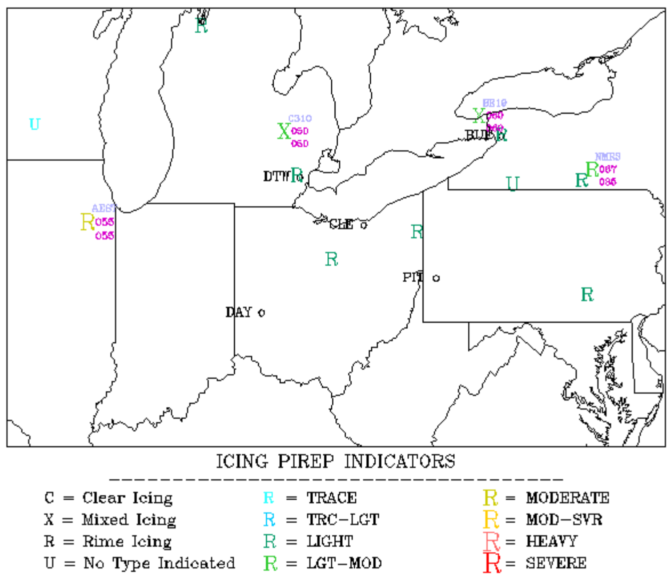


Figure 7 – Pilot reports of icing for 980305, e) 1800-1859 and f) 1900-1959 UTC.

PIREPS FOR THE PERIOD 980305/2000-2059



PIREPS FOR THE PERIOD 980305/2100-2159

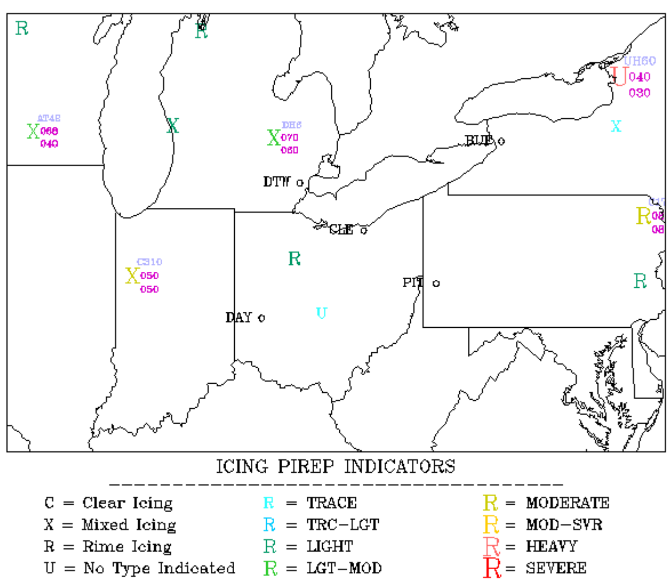


Figure 7 – Pilot reports of icing for 980305, g) 2000-2059 and h) 2100-2159 UTC.

March 18, 1998

Flight #1—Over Toledo, OH, Fort Wayne, IN, and Findlay, OH, from 1349 to 1551 UTC.
Flight #2—From Findlay to Cleveland, OH, between 1647 and 1729 UTC.

Brief overview

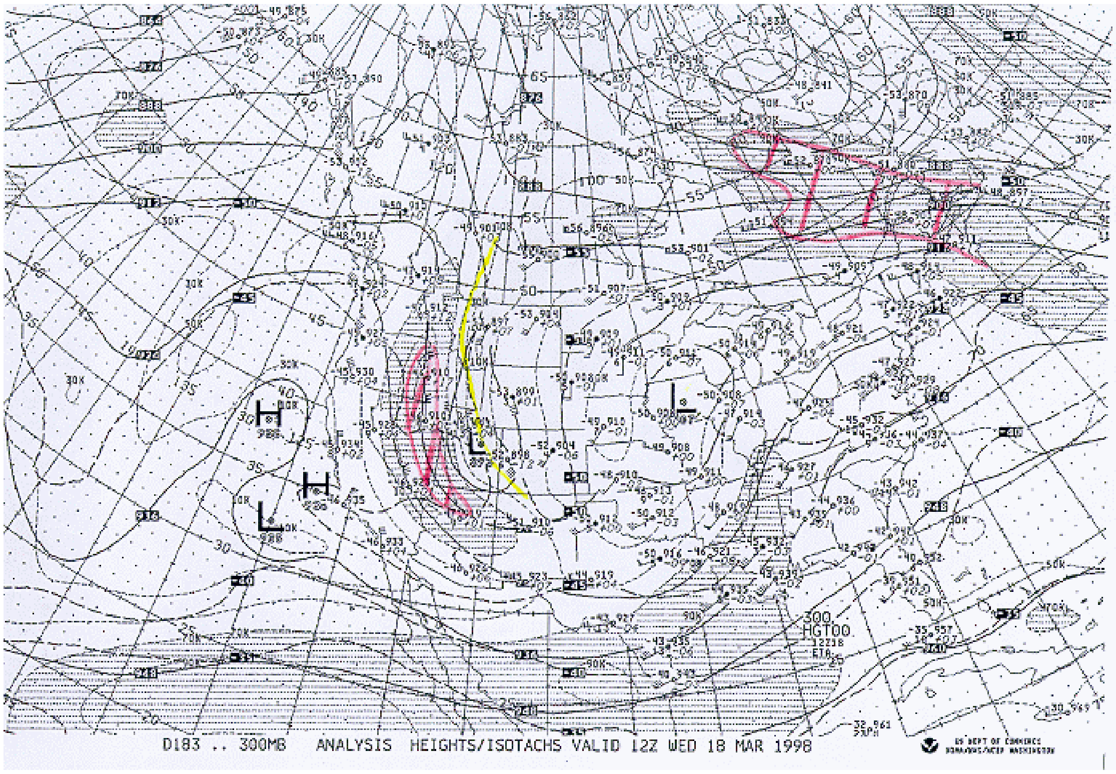
On this day, two flights were made into snow, mixed conditions, and a few pockets of all-liquid clouds within and on the fringes of widespread precipitation. During the first flight, some warm drizzle and rain that formed via melting was observed within and below clouds over Cleveland. The above-freezing low clouds were in layers, and contained LWC as high as 0.3. The freezing level was at 8300', and snow was observed from 7500' (T=+1.5C) to 12,000'. Mostly snow (including aggregates and large ice crystals) and low LWC (< 0.1) was observed during the majority of the time flown above the freezing level. However, near the Indiana/Ohio border there were a few pockets where the snow was not present, and the LWC rose to as high as 0.4. This occurred at altitudes around 11,000', where temperatures were near –3C. This icing was not of great interest, so the Twin Otter turned back to the east and landed at Findlay. The second flight was a quick jaunt from Findlay back to Cleveland. A layer of cloud with LWC up to 0.25 and CTT of +9C was observed between 1900' and 2700' over Findlay, and a few brief pockets of LWC up to 0.1 were found along the way.

Relevant weather features

At 1200 UTC, a 300 mb low was centered over Iowa, while a strong second low was over Utah (Fig. 1). Both lows were closed, and were joined by a common trough at 700 mb. Saturated 500 mb air was present across northern Michigan, as well as places to the east of Detroit and Indianapolis. Dry air pushed northward into Indiana and southwestern Michigan, where warm advection occurred over Ohio and Michigan. The warm advection was more clearly distinguishable at 700 mb in the same locations, as well as across the mid-Atlantic states and Wisconsin. Saturated air covered the entire forecast area at 700 and 850 mb. The eastern low was centered over Iowa at all levels. The 1200 UTC surface chart (Fig. 2) also had a low over Iowa, though it was positioned slightly to the east of the upper lows. The surface low was weak (1007 mb), but strong 1041 mb and 1034 mb highs to the north of Minnesota, and east of Rhode Island set up good pressure gradients across the forecast area. A cold front ran southward to the Texas coast, while an occluded/warm front curled southeastward through Indiana and a trough/stationary front extended eastward across the southern Michigan border. The entire setup was stagnant, and showed little movement over the next six hours.

Surface observations and radar mosaics (Figs. 2, 3) showed widespread rain to the north of the trough/stationary front, with freezing rain and snow over northern Michigan and northern Wisconsin. Overcast skies and large patches of rain were observed to the south of the trough/front. Sounding data from Detroit showed deep cloud there, with CTTs < -20C (Fig. 4). Veering winds provided evidence that warm advection was present in the lowest 10,000 feet. Also, the classical freezing rain temperature structure was

nearly present in the Detroit sounding, with temperatures up to +6C at 880 mb, and down to +1C at the surface. The Alpena sounding was similar, but perhaps slightly too cold to cause freezing rain to form, with temperatures only reaching 0C at 850 mb and -4C at 920 mb. In between, a freezing rain layer was likely to exist, and this nicely matched the surface observations in northern Michigan at 1200 UTC. The Wilmington sounding had clouds above the 750 mb freezing level. CTTs were much colder than -20C there, but a bit of drying was present near 800 mb, possibly explaining some of the breaks in the precipitation shield over Ohio. Satellite data were only available for 1215 and 1345 UTC for this case (Fig. 5). The 1215 UTC infrared image showed breaks in the clouds over eastern Ohio, while most of Indiana, Michigan, and the rest of Ohio were enveloped in deep, cold clouds. Cloud tops were quite variable, with CTTs ranging from -50C to about –15C. Icing PIREPs were sparse across the region, except for a couple reporting moderate rime and one of light-to-moderate mixed between 14,000 and 18,000 feet (Fig. 6). Some light icing was scattered about as well.



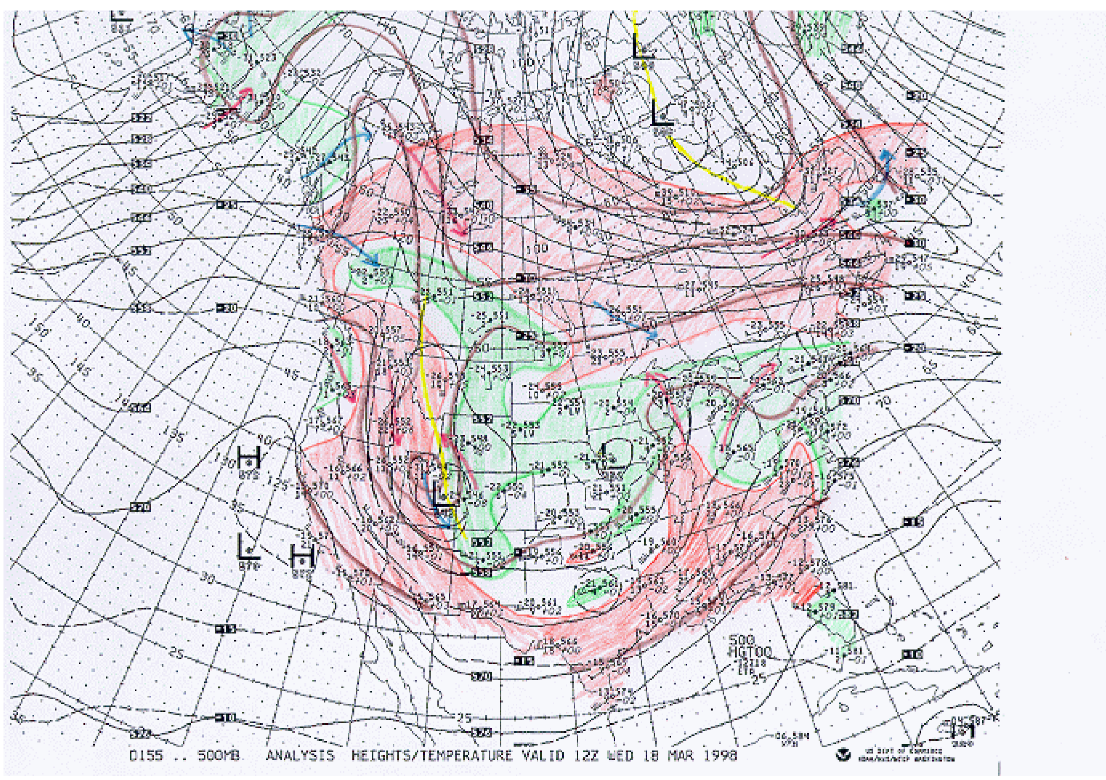
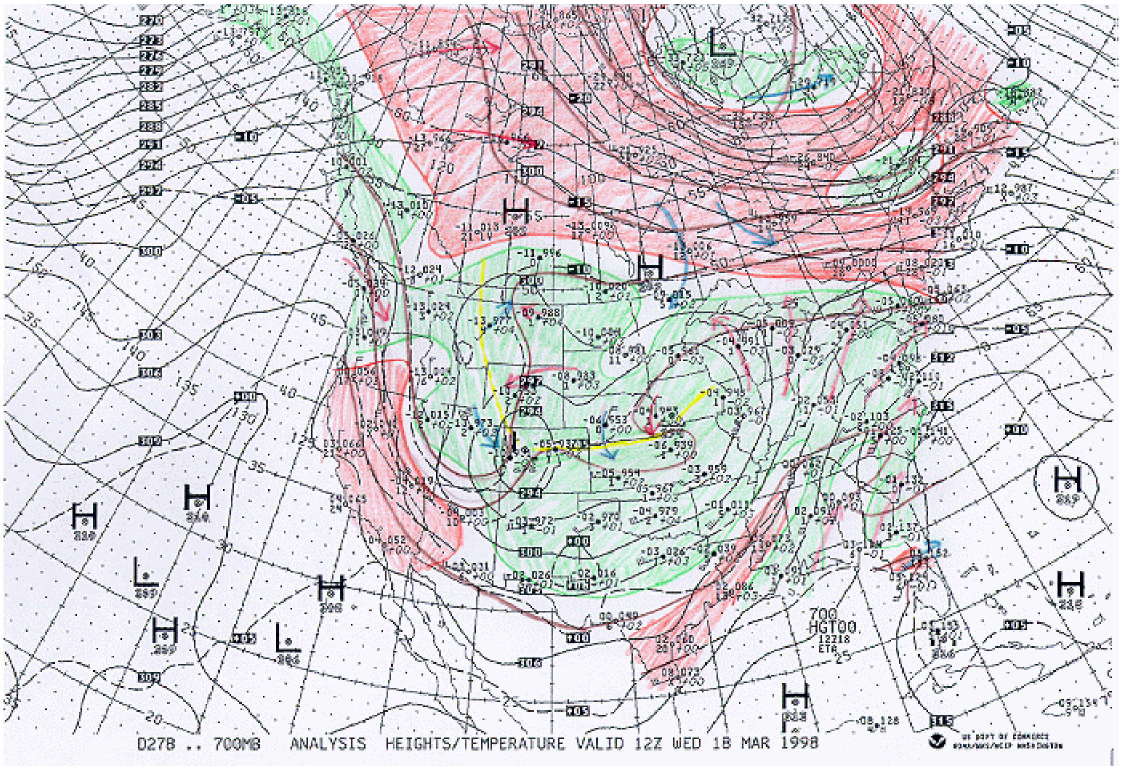


Figure 1 – Upper-air charts for 980318, 1200 UTC at a) 300 and b) 500 mb.



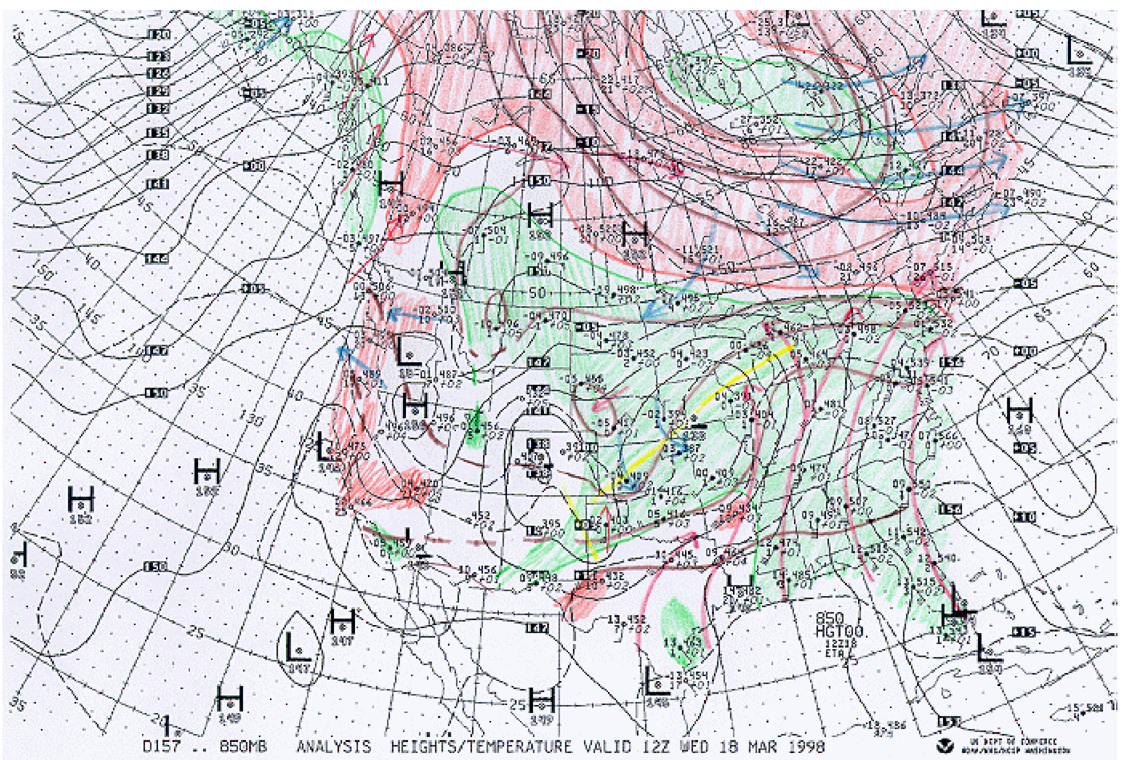


Figure 1 – Upper-air charts for 980318, 1200 UTC at c) 700 and d) 850 mb.

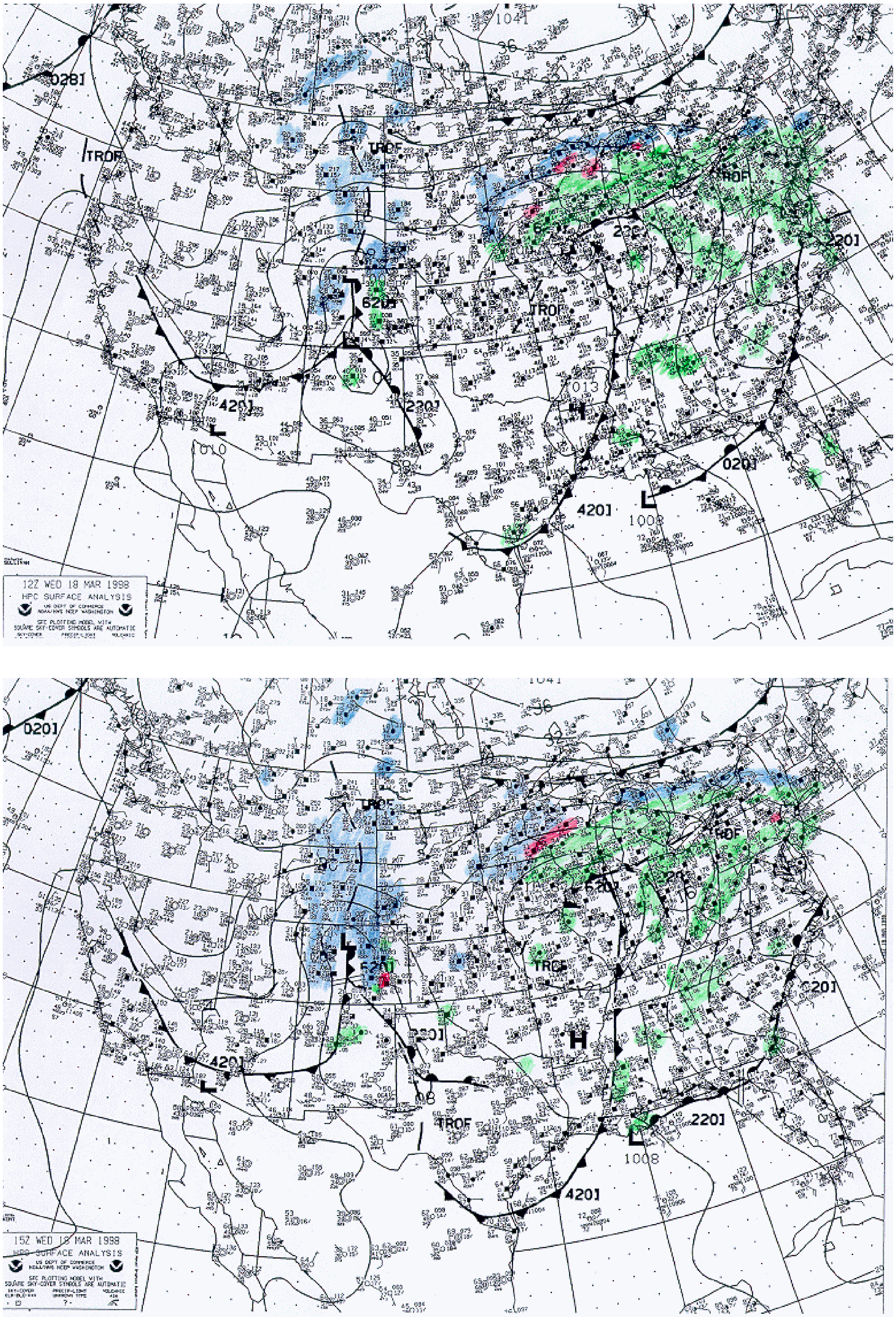
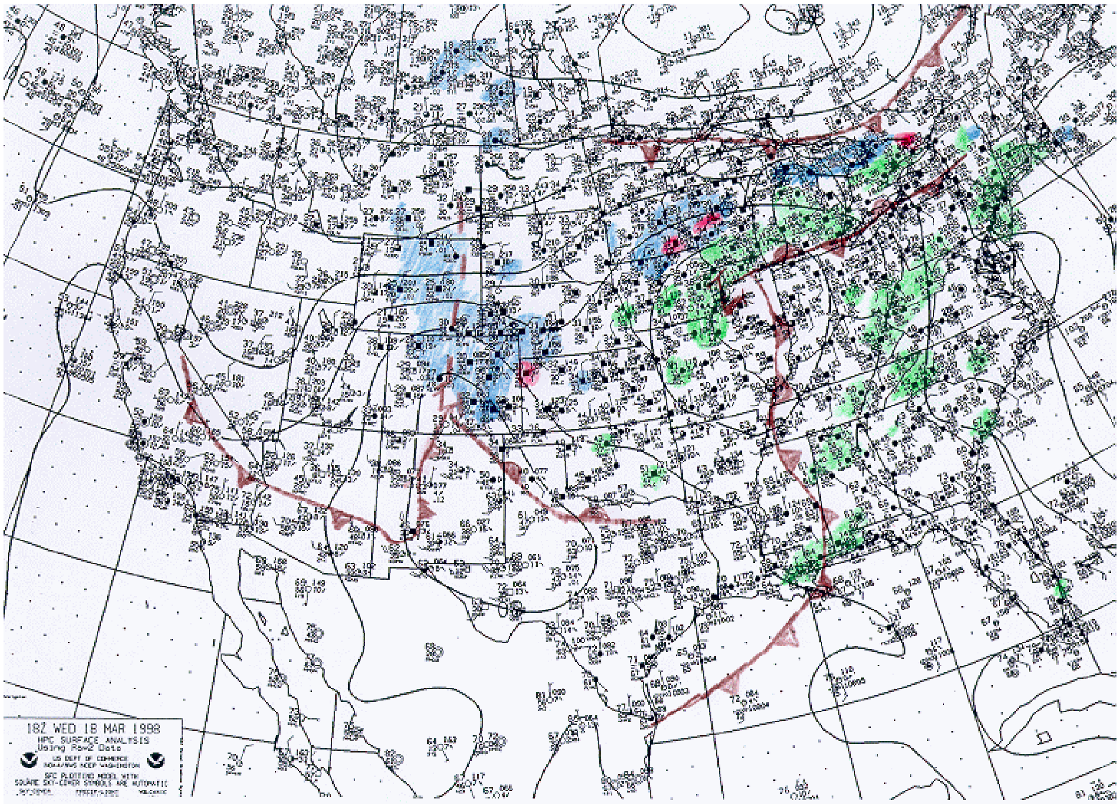


Figure 2 – Surface charts for 980318, a) 1200 and b) 1500 UTC.



RADAR DATA PLOT FOR 980318 AT 13 Z

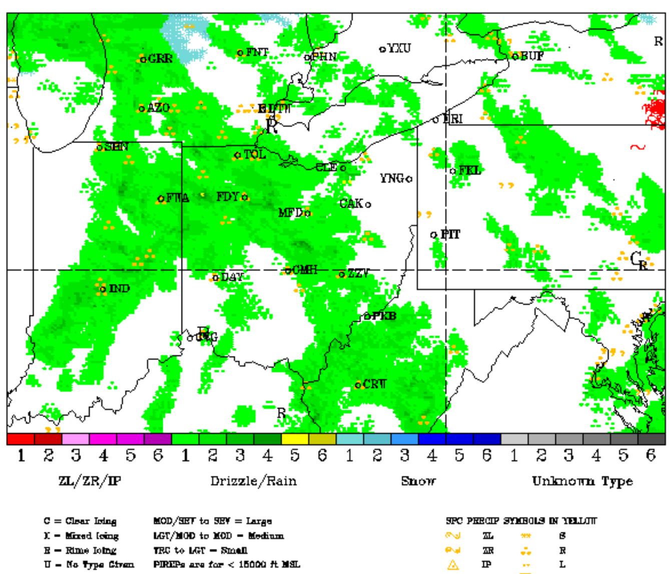
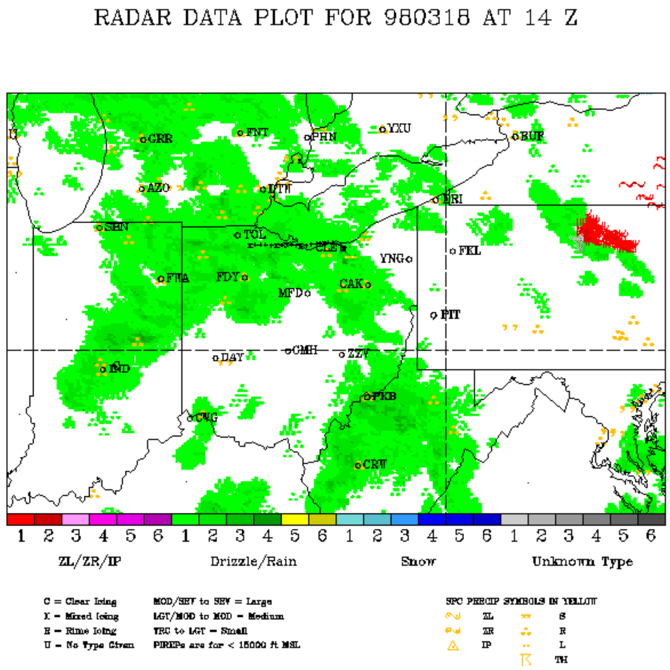


Figure 2 – Surface chart for 980318, c) 1800 UTC.
Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980318, a) 1300 UTC.



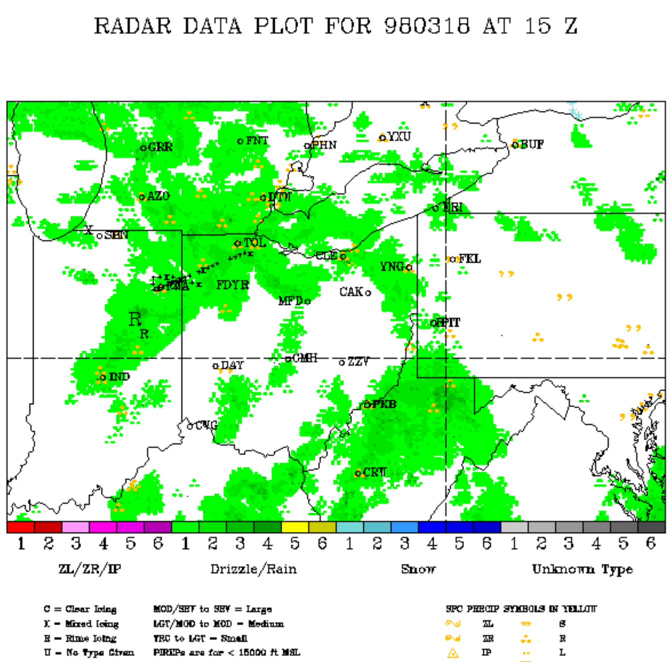
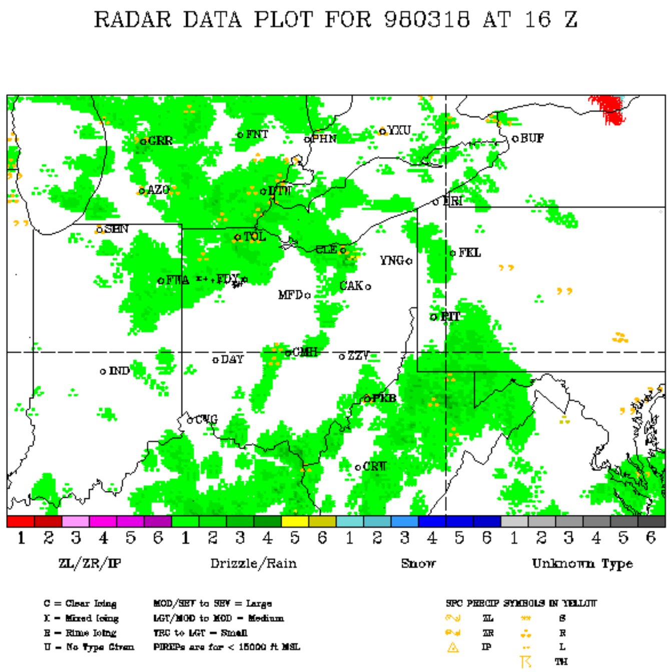


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980318, b) 1400 and c) 1500 UTC.



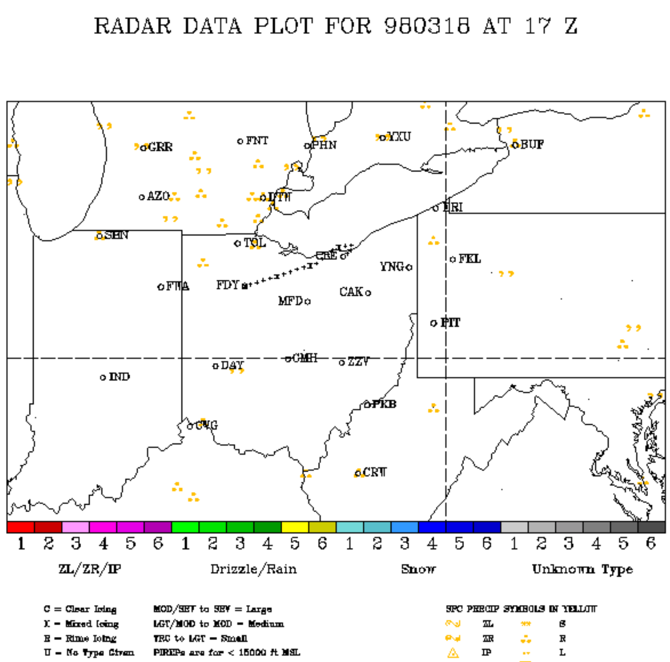
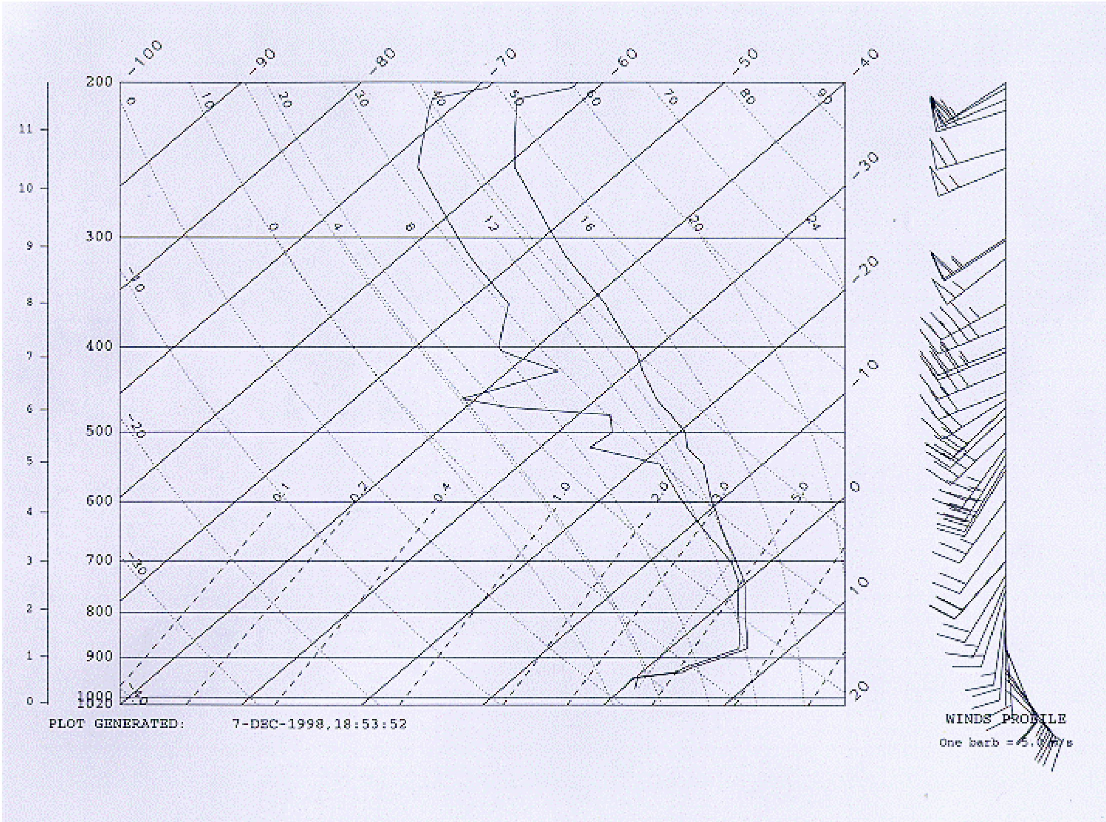


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980318, d) 1600 and e) 1700 UTC. Radar data missing for 1700 UTC – all other data is shown.



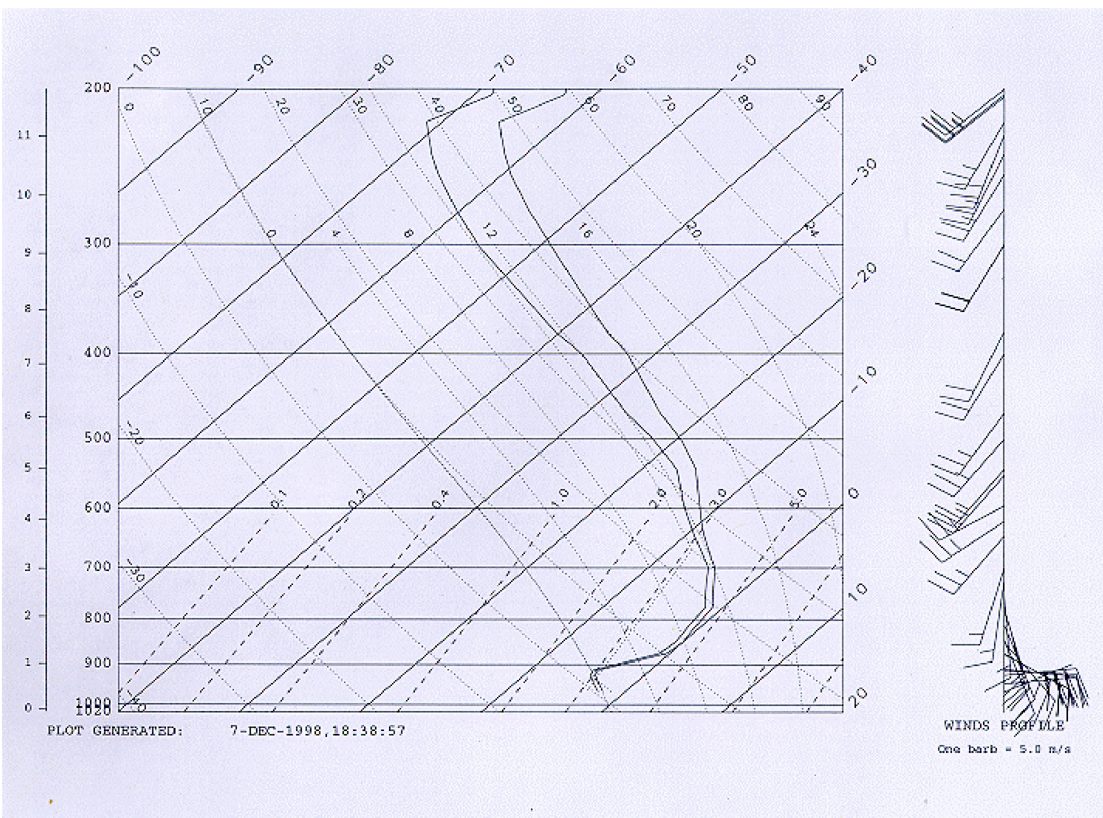
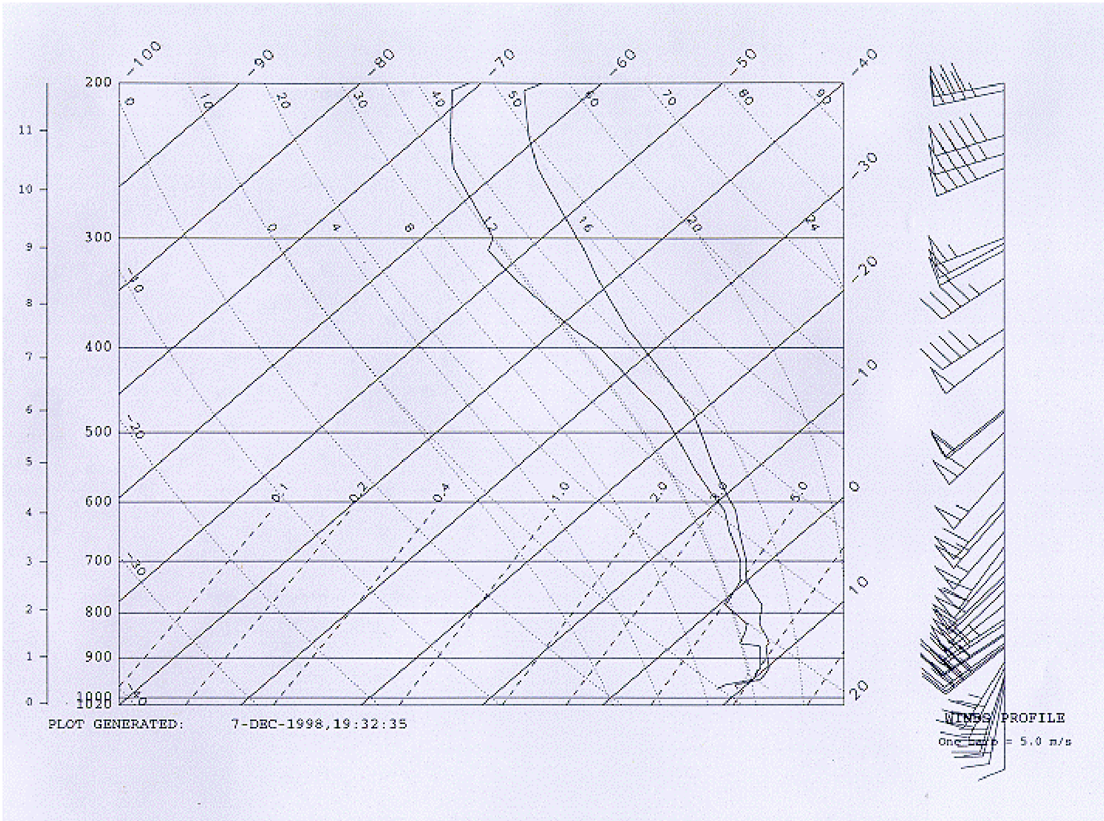


Figure 4 – Balloon-borne soundings from a) Detroit and b) Alpena MI at 980318, 1200 UTC.



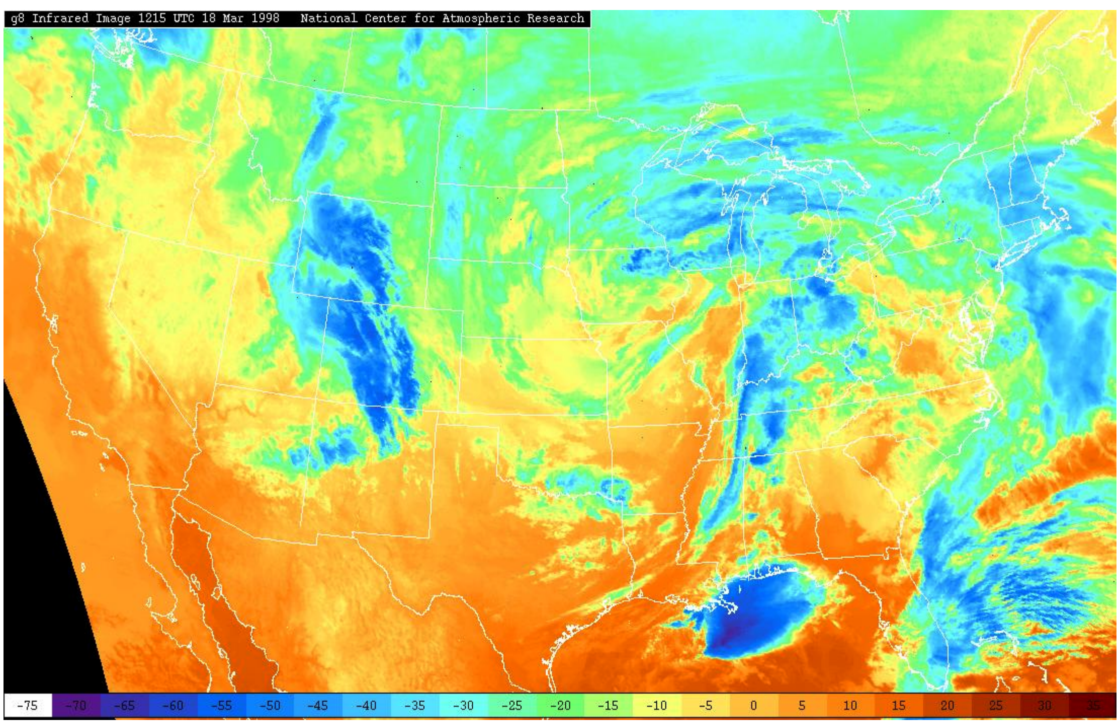
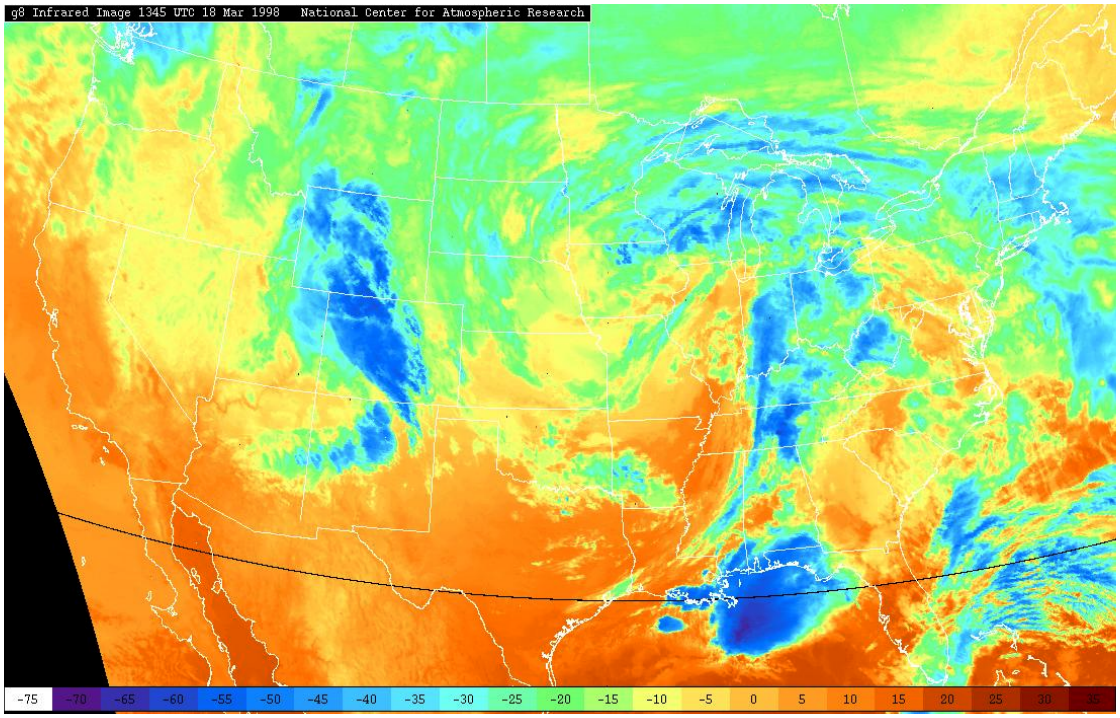


Figure 4 – Balloon-borne sounding from c) Wilmington at 980318, 1200 UTC.
Figure 5 – GOES-8 a) infrared satellite image for 980318, 1215 UTC.



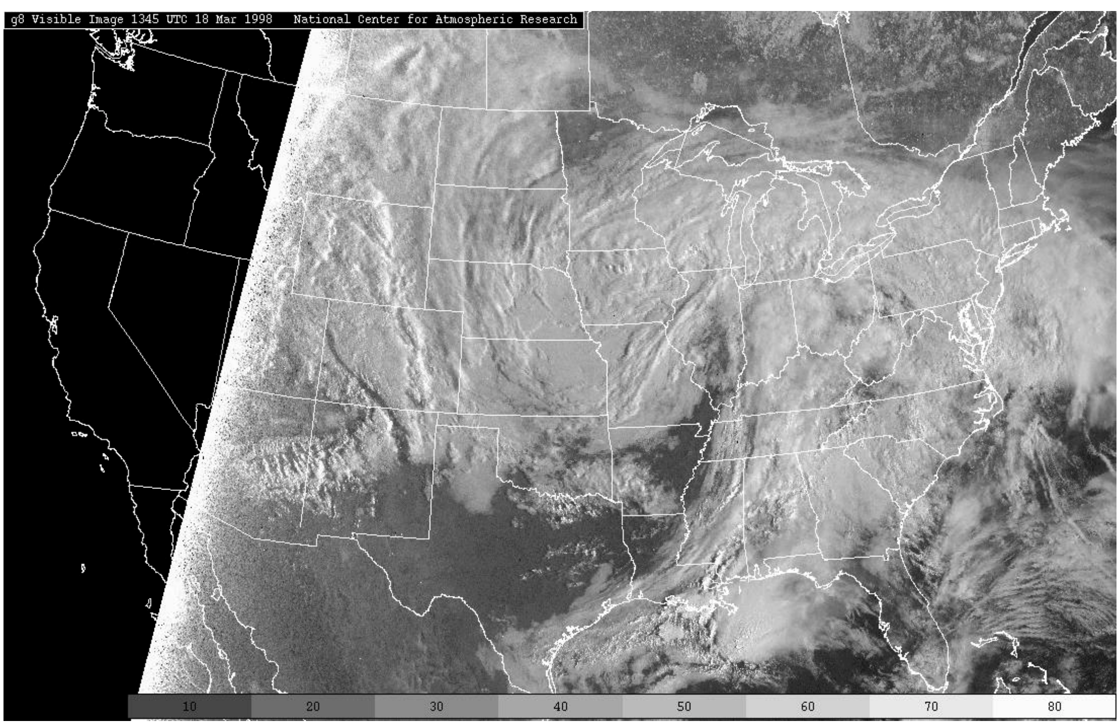
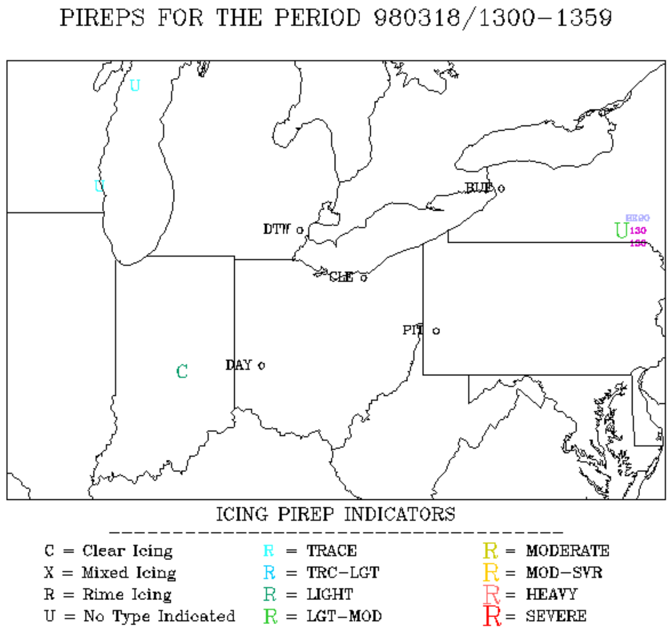


Figure 5 – GOES-8 b) infrared and c) visible satellite images for 980318, 1345 UTC.



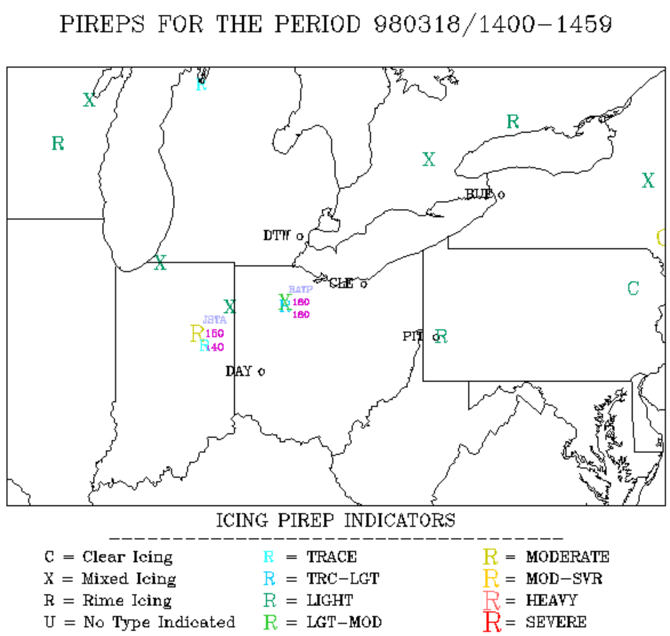
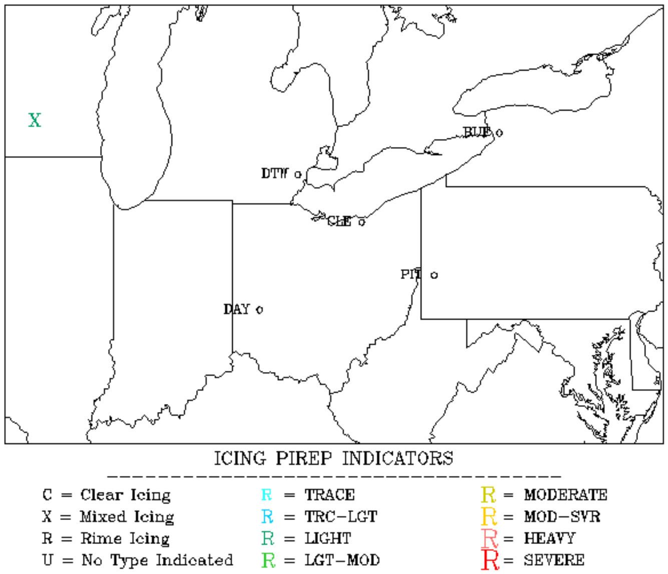


Figure 6 – Pilot reports of icing for 980318, a) 1300-1359 and b) 1400-1459 UTC.

PIREPS FOR THE PERIOD 980318/1500-1559



PIREPS FOR THE PERIOD 980318/1600-1659

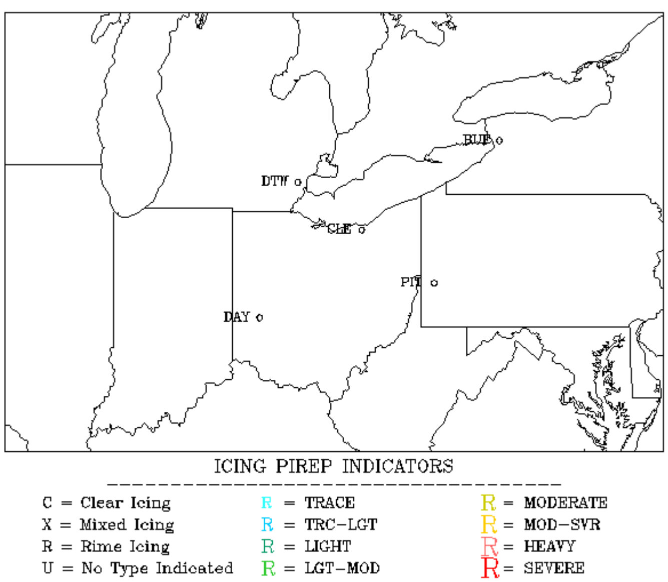


Figure 6 – Pilot reports of icing for 980318, c) 1500-1559 and d) 1600-1659 UTC.

March 20, 1998

Flight #1—Over Findlay, OH, and Fort Wayne, IN, from 1438 to 1614 UTC.

Flight #2—Over Fort Wayne, IN, and Kalamazoo, MI, from 1725 to 1820 UTC.

Flight #3—Over Kalamazoo, MI, from 1905 to 2042 UTC.

Flight #4—Over Battle Creek, MI, and Toledo, OH, from 2130 to 2306 UTC.

Brief overview

Four flights were made on this day to investigate classical freezing rain (ZR) and freezing drizzle (ZL) surrounding the southern border of Michigan. Noise in the 2D-Grey probe data was a problem at times, and the entire second flight had no 2D-Grey data. During the first flight, some warm clouds (T near 0C) with low LWC (up to 0.1) were found near Sandusky. A classical ZR temperature structure was evident as far east as Findlay, but no precipitation fell there. However, LWC was as high as 0.4 in small-drop clouds with temperatures near –3C near 3000’. Light ZR and ZL were first encountered about half way between Findlay and Fort Wayne. Drop sizes fluctuated between the ZR and ZL ranges around the Ohio/Indiana border, but became more solid, consistent ZR near Fort Wayne. Soundings made during the first flight showed that snow falling from above was still present at 6200’, despite temperatures of +3C. Complete melting of the snow had occurred by 5800’, where the maximum temperature of +3.6C was reached. The lower “re-freezing level” was at 4200’, and temperatures quickly fell to –4C by 3200’. Subfreezing temperatures extended to the surface at Fort Wayne. Clouds did not extend through this entire range of altitudes. Cloud decks were present between 2200’ and 3500’ (CTT = -2C, LWC_{max}=0.2), and somewhere above 6200’ (no other clouds indicated up to that altitude, but snow was falling from above, so higher clouds had to exist). During the second flight, the Twin Otter sampled very similar, but slightly colder (T=-5C at 3400’) conditions near Elkhart and Kalamazoo (AZO). The aircraft landed at Battle Creek after only one hour due to 2D-Grey probe problems. Unfortunately, this is the period when the best conditions appeared to be exist.

During the third flight, the 2D-Grey probe was operable, and a series of northwest-to-southeast and west-to-east transects and soundings were made over and to the southeast of AZO. Temperatures were slightly colder (T=-6C at 3000’) within the ZR layer, which extended from roughly 5000’ to the surface (1000’ MSL). AZO was located at or just to the north of the northern end of the melting zone/warm nose. A sounding taken there revealed maximum temperatures of –0.1C at 5000’ and aggregates of snow from 3000’ up to 10,200’ (T=-3.2C there). A melting zone was observed between 7200’ and 5000’ just to the southeast of AZO, with a maximum temperature of +0.9C at 5500’. However, incomplete melting was occurring there, and snow continued down into the ZR/ZL layer. Ice pellets may have also been present. Transects revealed snow (aggregates) over AZO, ZR mixed with aggregates just to the southeast, and ZL mixed with ice crystals (columns) at the Michigan/Indiana border. Clouds continued to be present in the lower subfreezing layer, and the LWC was lowest (near 0) and highest (near 0.2) at the northwest and southeast/east ends of the transects, respectively.

The fourth flight was essentially a ferry flight back to Cleveland. Snow (aggregates) were observed upon takeoff from Battle Creek, and some small-droplets were mixed in (LWC ~0.05) near 3000’. A layer of temperatures between –0.2 and +0.2 existed between 5500’ and 7200’ (maximum altitude reached). The Twin Otter remained at 7100’ and flew past Jackson MI in a mixture of aggregates and columns. Small droplets began to show up near the Michigan/Ohio border, and LWC values reached 0.5 near Toledo, but occasional ice crystals and possibly a little drizzle were present at times. The LWC was somewhat wavy, but rather irregular. Ice crystals/snow became inconsistent as well, while crystal and aggregate sizes shrunk. The ice crystals essentially disappeared to the southeast of Toledo. Temperatures remained near 0C at 7200’. The LWC varied greatly during the remaining portion of the flight, with values ranging from 0 to 0.5Ice crystals suddenly became rather prevalent near Cleveland. The snow/ice crystals melted to become light rain below 6000’ and this rain was observed down to the surface during the final descent.

Relevant weather features

At 1200 UTC, a closed low was centered over western Kentucky and Tennessee at 300 mb and 500 mb (Fig. 1). A trough ran northward to the Michigan-Indiana border from the 500 mb low. Saturated air with temperatures near -20C covered areas to the north of the low, including western Ohio, Indiana, and most of Illinois. Dry air was present elsewhere. The low was stronger at 700 mb, with a trough that connected to a low over Quebec, and slightly more widespread moisture that extended to just north of the Indiana/Michigan border. Cold advection was present across Michigan and Wisconsin, while a warm wedge of air had moved into Illinois, Indiana, and Ohio. This trend continued at 850 mb with an even stronger low over the southern tip of Illinois, the trough across northern Indiana and southeastern Michigan, strong cold advection over Michigan, and strong warm advection over northern Indiana and northern Ohio. Moisture was abundant at this level an extended into northern Michigan. The entire pattern shifted slowly to the east and weakened a bit by 0000 UTC (Fig. 2). The 500 mb moisture pushed slightly northward into southern Michigan, while dry air punched into southwestern Ohio. The trough axis slid a bit to the east, and the battle between warm and cold advection at 700 and 850 mb moved to the Ohio-Michigan border.

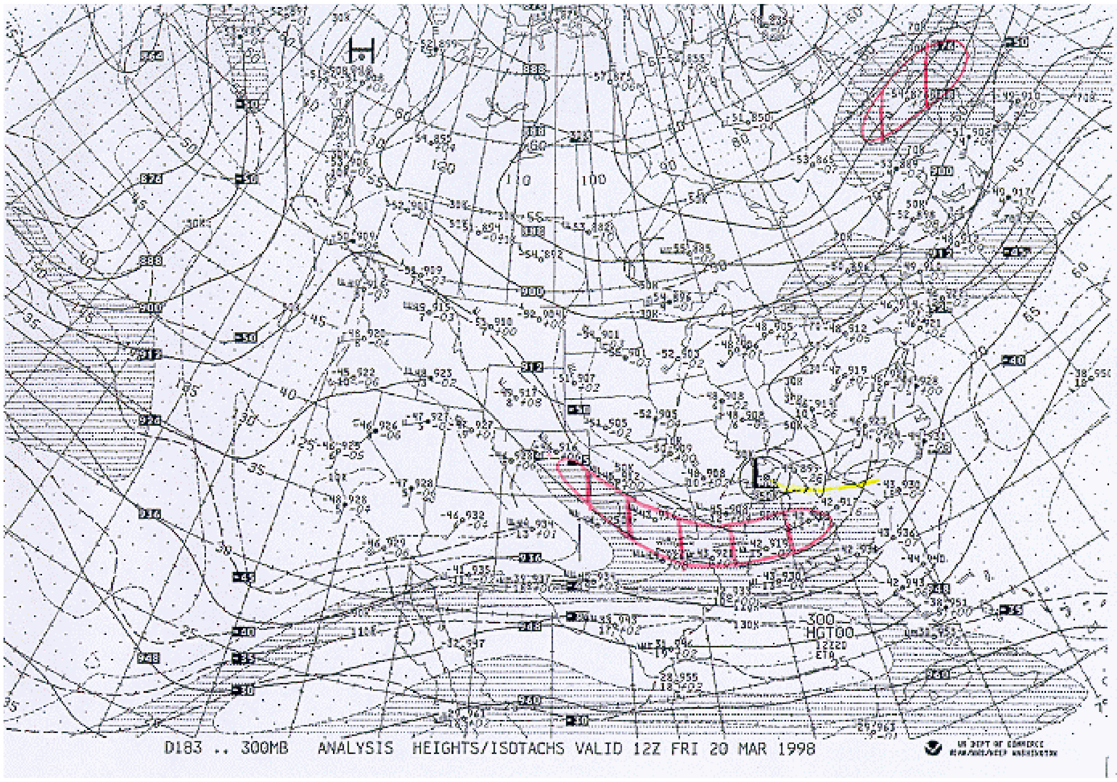
At the surface, a fairly complicated pattern had set up (Fig. 3). A 998 mb occluding low was centered over the Indiana-Kentucky border, and featured a stationary front that draped across southern Ohio and central Pennsylvania. An occluded front sat over central Kentucky, then split into cold and warm fronts that went to the south and east, respectively. Cold, dry air funneled across Wisconsin, Michigan, and Ontario toward the low, while warm air from the south overran the cold air to the north of the low and the stationary front. At 1500 UTC, light to moderate rain fell across southern Illinois, Indiana, and western Ohio, while snow fell on the northwestern fringe of precipitation in northern Illinois and Missouri (Fig. 4). Bits of freezing rain and ice pellets popped up along the rain/snow interface and the northern end of the rain in southern Michigan. Temperatures at the surface were essentially 0C on the Michigan-Indiana border. With time, the low and associated precipitation eked eastward, while areas of freezing rain and ice

pellets expanded over northern Indiana and southern Michigan. Some snow developed in a few places just to the northwest of there.

Satellite imagery (Fig. 5) show that deep, cold clouds extended slightly further to the north than the precipitation shield, giving evidence of the dry Arctic air that undercut the deep moisture. Otherwise, the cold cloud tops nicely matched the precipitation locations on the northern and western sides of the storm. The clouds pushed further to the north across Michigan during the day, matching the slow northward encroachment of the precipitation shield. The dry slot shown on the 0000 UTC 500 mb chart was quite evident in the visible and infrared signatures over southern Indiana and southwestern Ohio at 2215 UTC.

Sounding data help to further clarify the situation (Fig. 6). To Detroit 1200 UTC sounding was only complete up to 700 mb, but the Arctic air was clearly evident via northeasterly winds and subfreezing temperatures to -6C (at 900 mb) beneath a strong inversion that reached 0 C at 820 mb. This structure was still present in the more complete 0000 UTC sounding, which had saturated conditions to the tropopause. Although the maximum temperature in the sounding was only -1C at 850 mb, observations of freezing rain and ice pellets at and around Detroit confirms the existence of a melting zone near 5000 feet. The 1200 UTC Lincoln sounding showed that the classical freezing rain structure also existed on the back side of the system, along the surface rain/snow boundary. Surface temperatures were just above 0 C at Lincoln, causing rain there, but freezing rain was observed nearby. As the warm push aloft moved eastward, the melting layer disappeared and the precipitation changed to snow there. The Aplena MI soundings showed the cold, dry air that was being drawn into this system from northern Michigan on northeasterly winds. Countering that were the warm, moist conditions being fed in from the south, as seen in the Wilmington soundings. The dry slot also shows up here at 0000 UTC, as cold cloud tops were eroded over southwestern Ohio, leading to liquid clouds with CTTs > -10C there.

PIREPs generally fell within two categories on this day (Fig. 7). Either they were moderate (and even severe) mostly clear and mixed icing in the freezing rain layer below 4500 feet or they were spotty, moderate (and even severe) rime icing above 13,000 feet in pockets and/or breaks in the deep precipitation shield. Patches of warmer cloud tops were co-located with some of these PIREPs. Others probably occurred in layered clouds or convective zones.



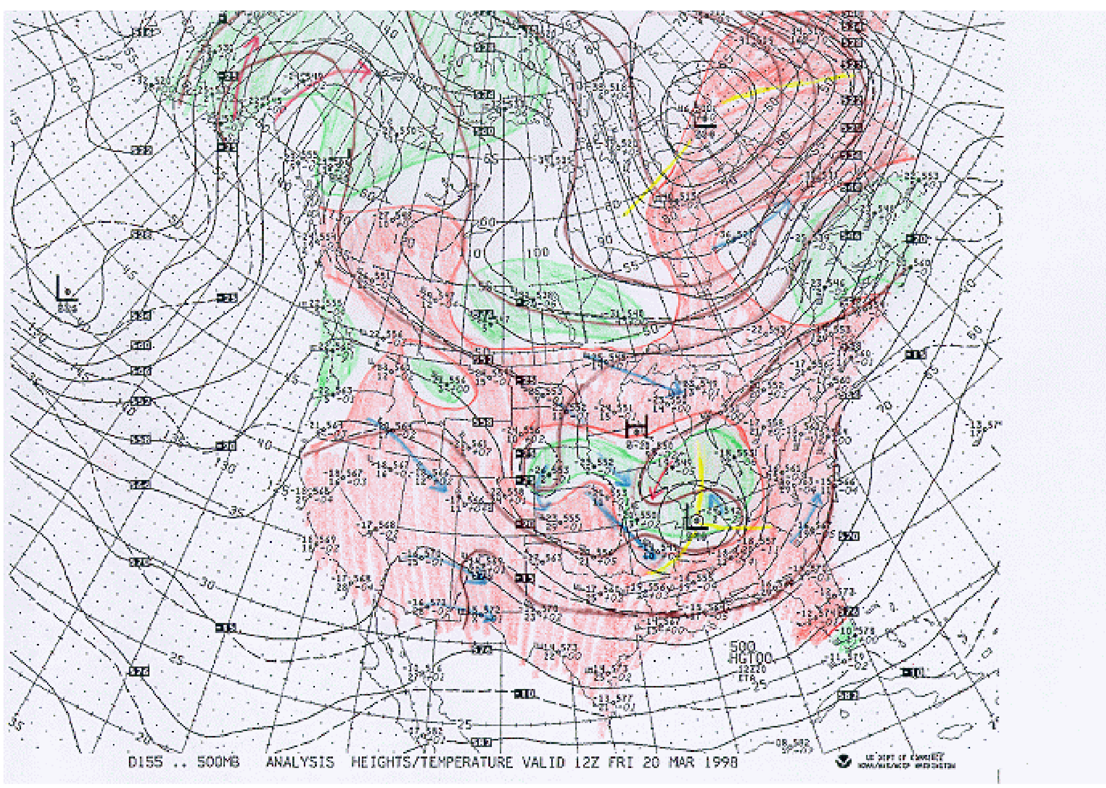
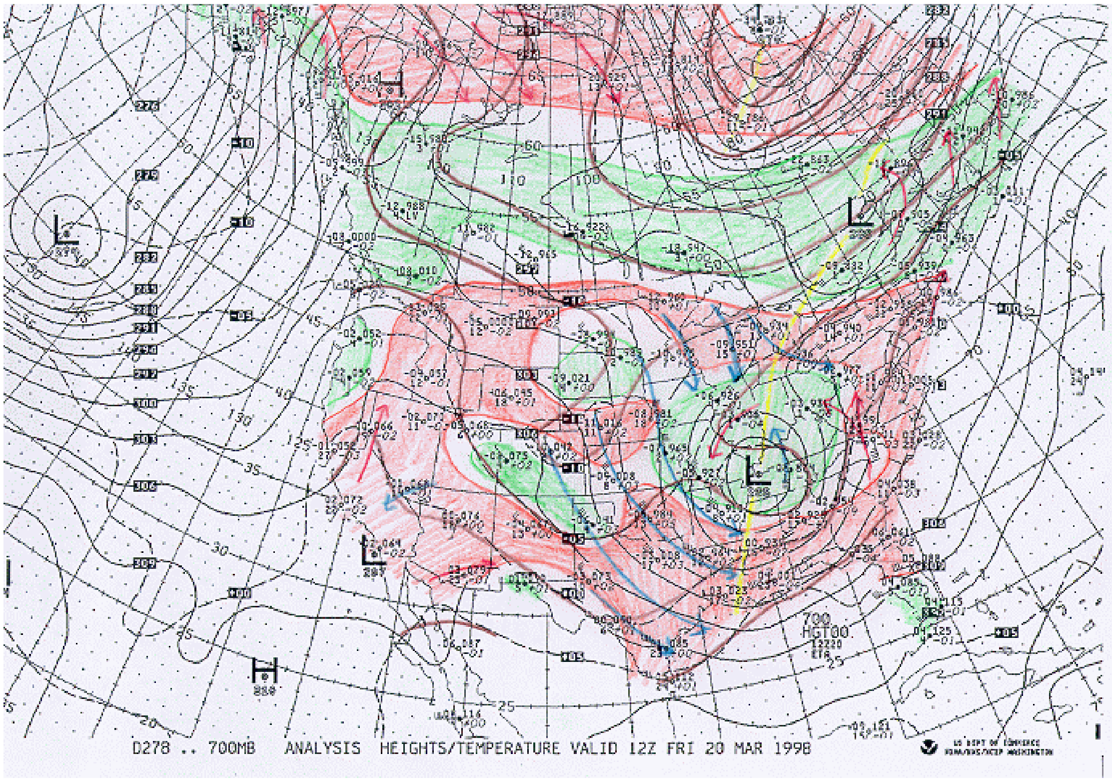


Figure 1 – Upper-air charts for 980320, 1200 UTC at a) 300 and b) 500 mb.



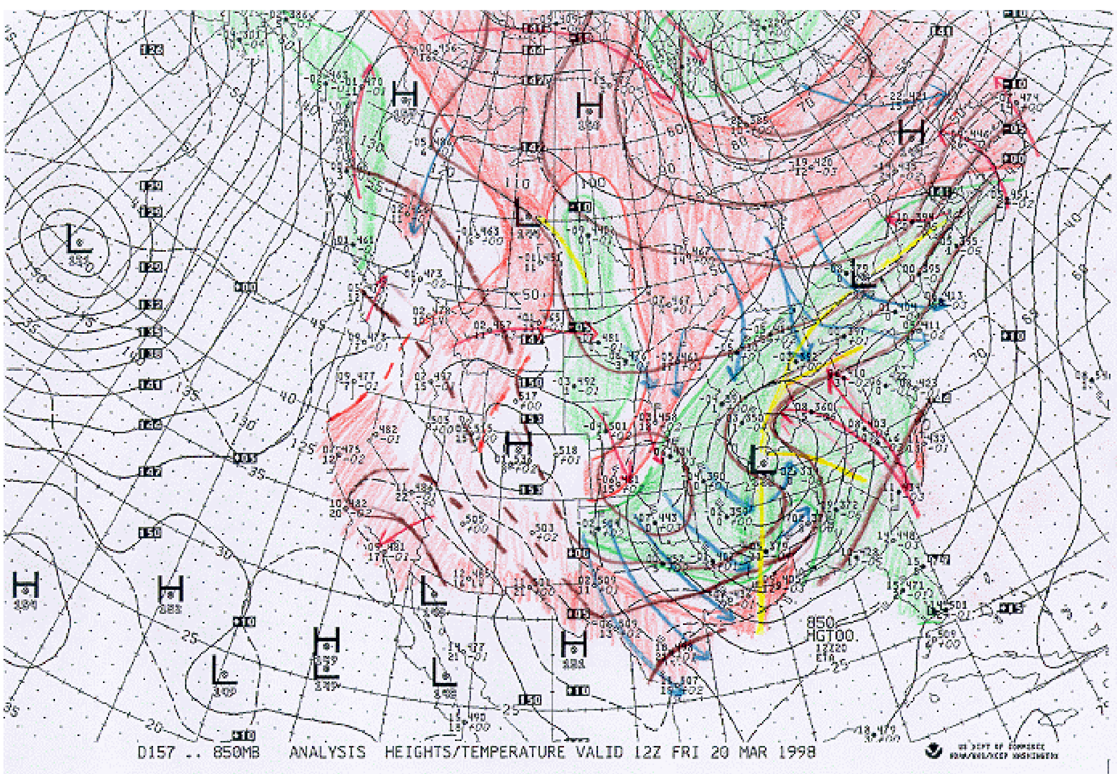


Figure 1 – Upper-air charts for 980320, 1200 UTC at c) 700 and d) 850 mb.

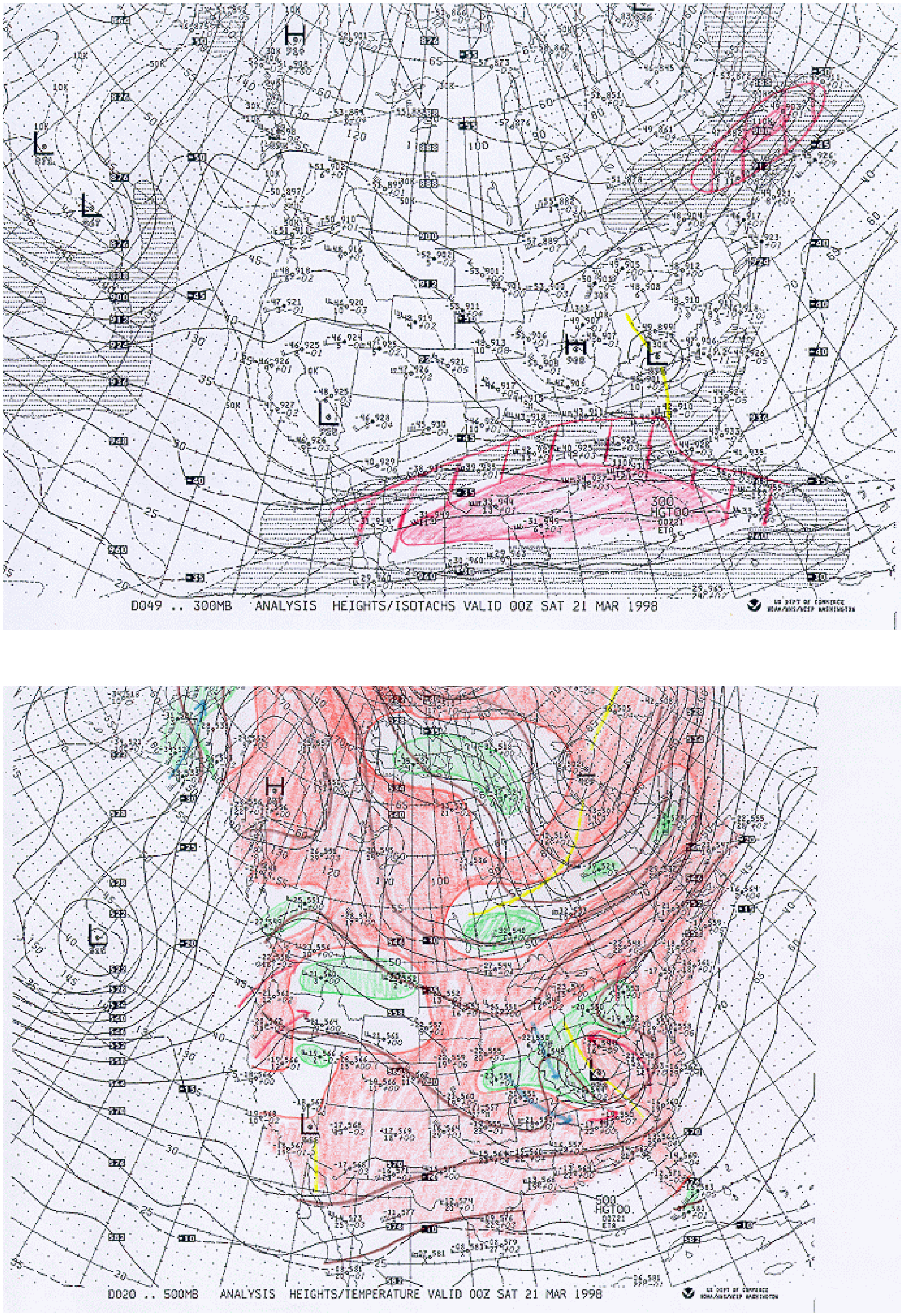
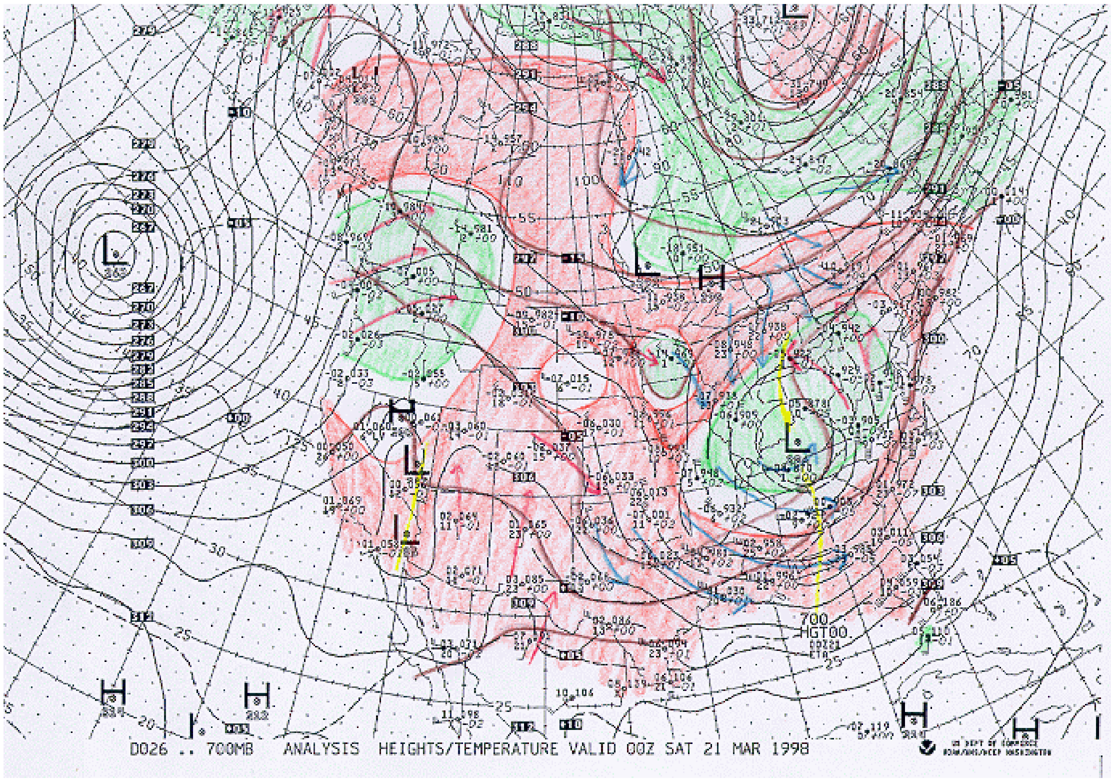


Figure 2 – Upper-air charts for 980321, 0000 UTC at a) 300 and b) 500 mb.



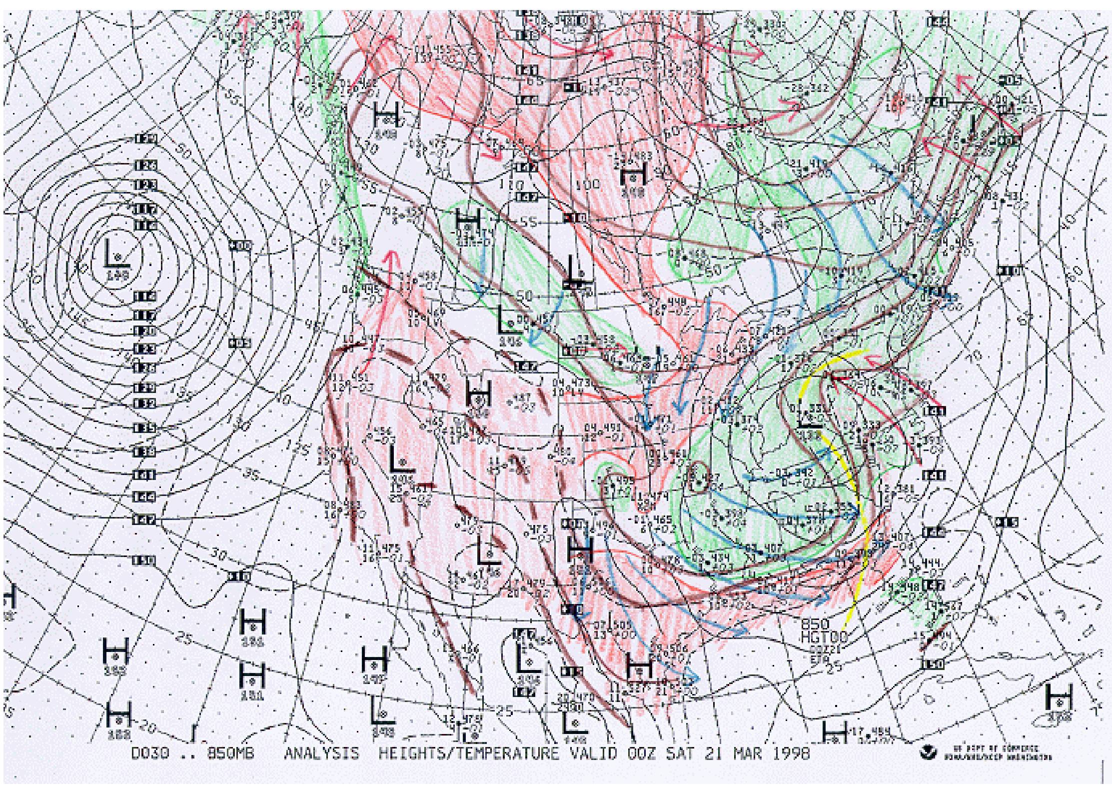


Figure 2 – Upper-air charts for 980321, 0000 UTC at c) 700 and d) 850 mb.

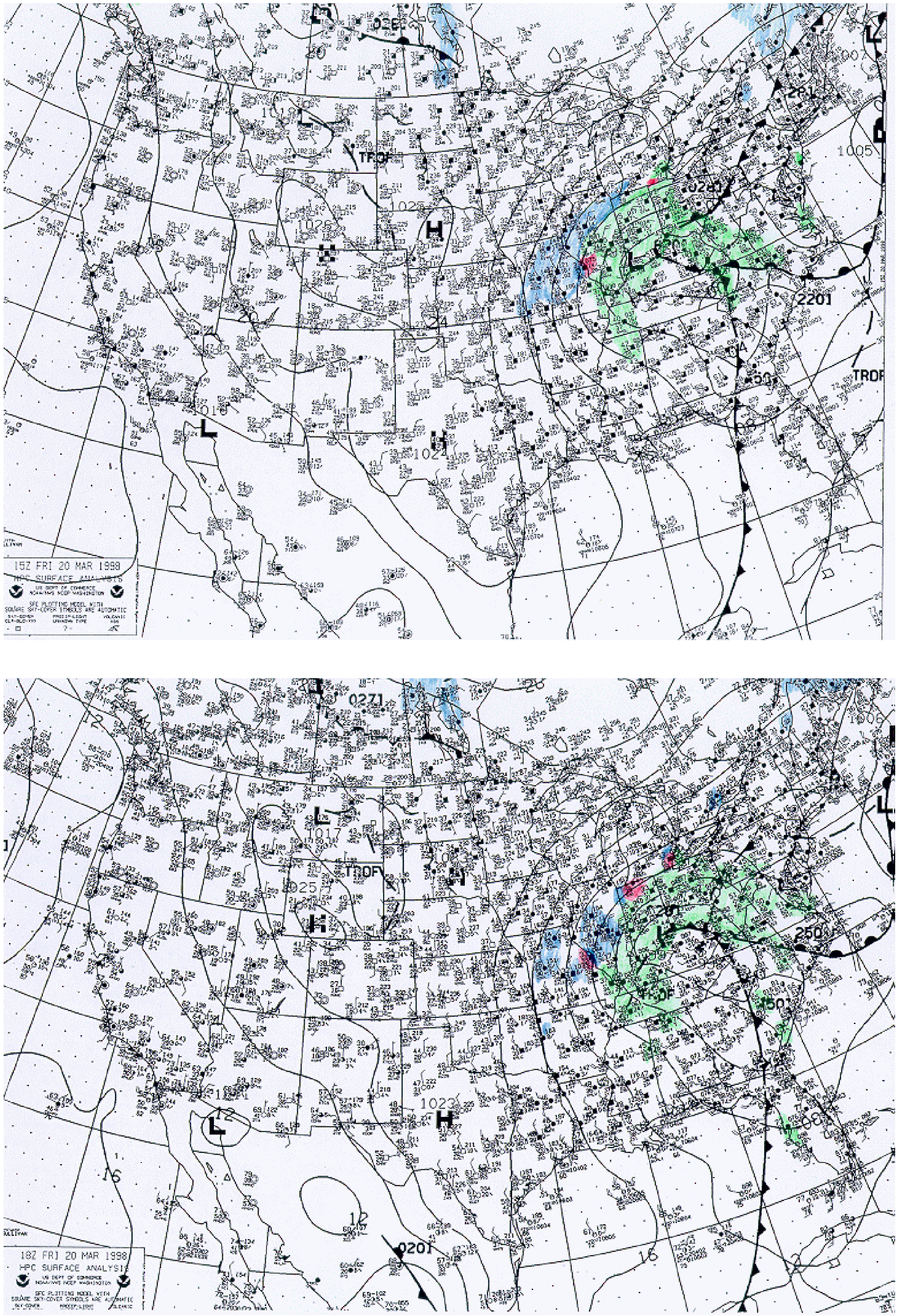
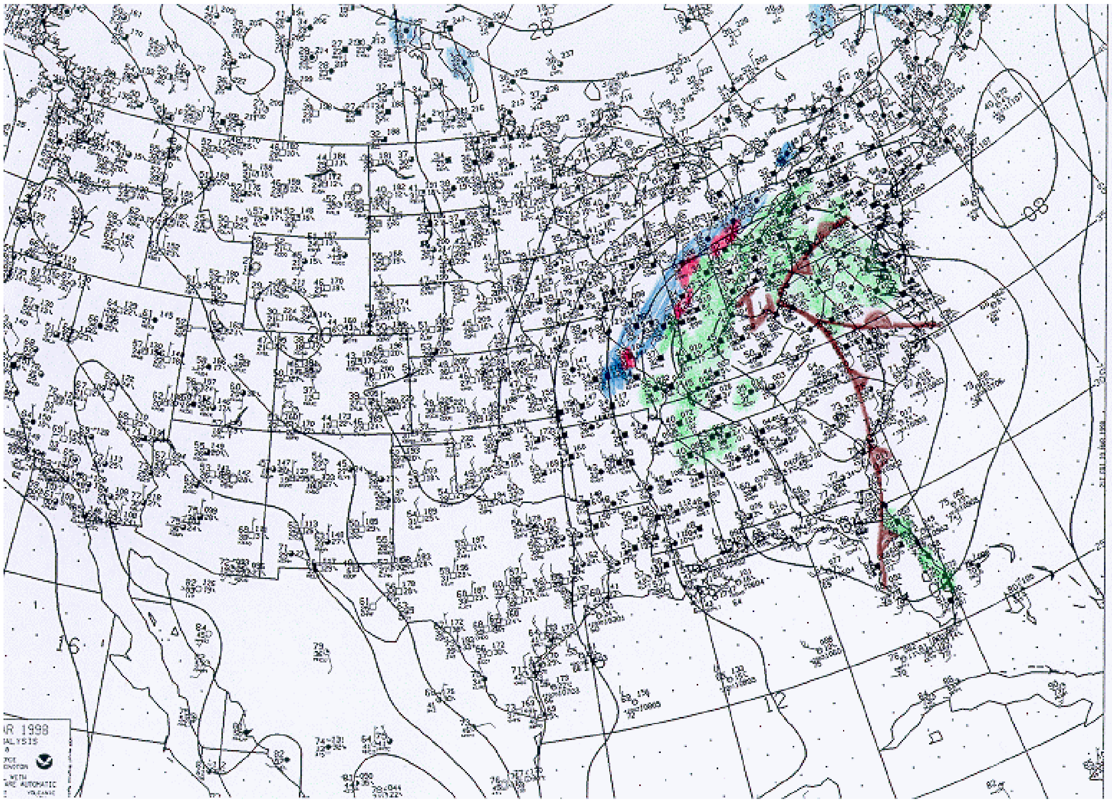


Figure 3 – Surface charts for 980320, a) 1500 and b) 1800 UTC.



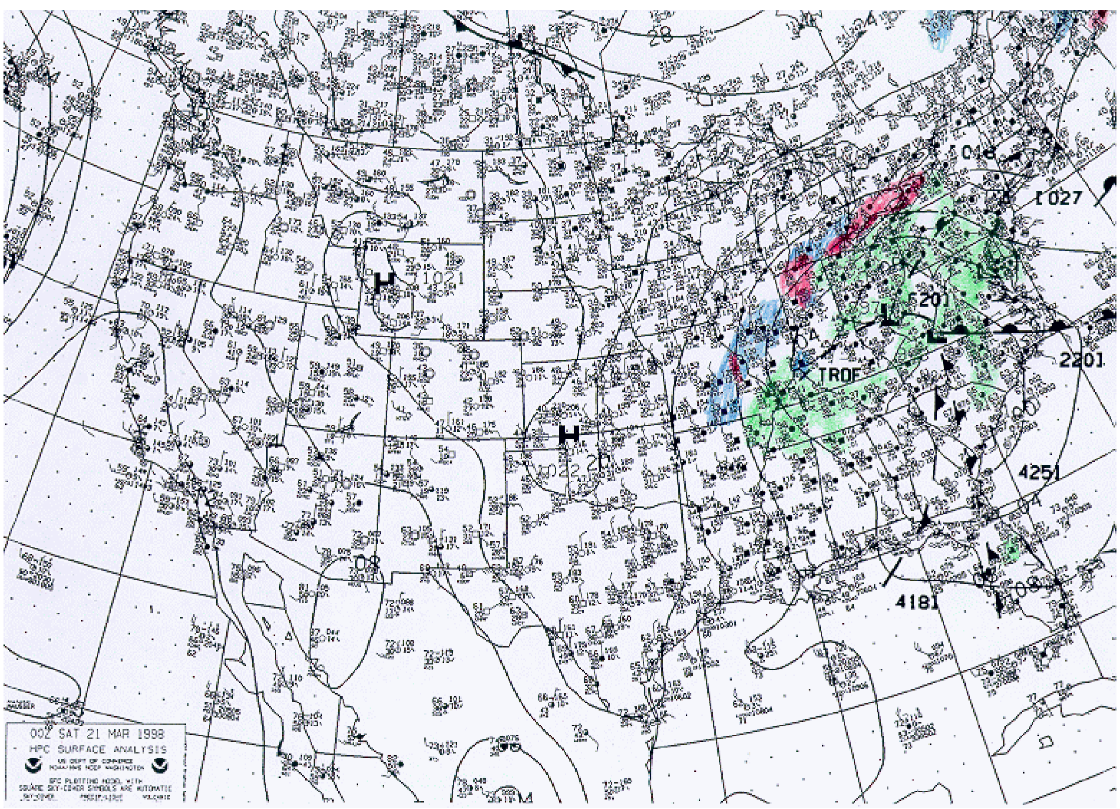
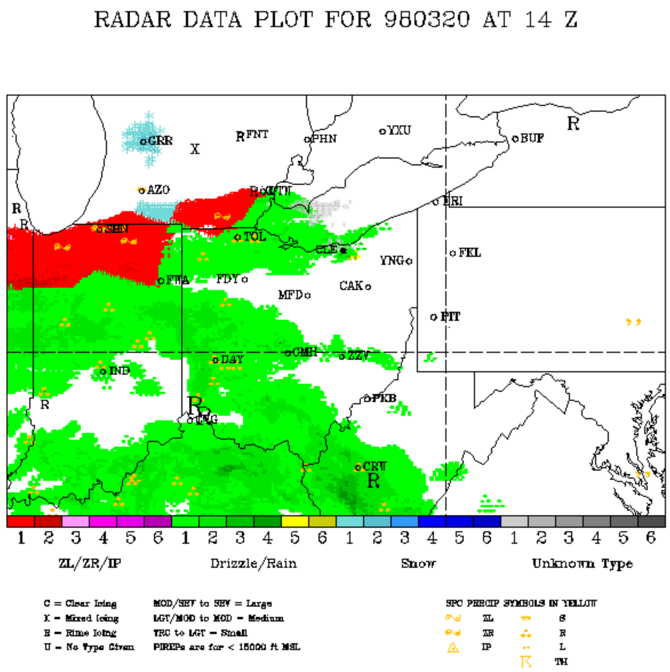


Figure 3 – Surface charts for c) 980320, 2100 and d) 980321, 0000 UTC.



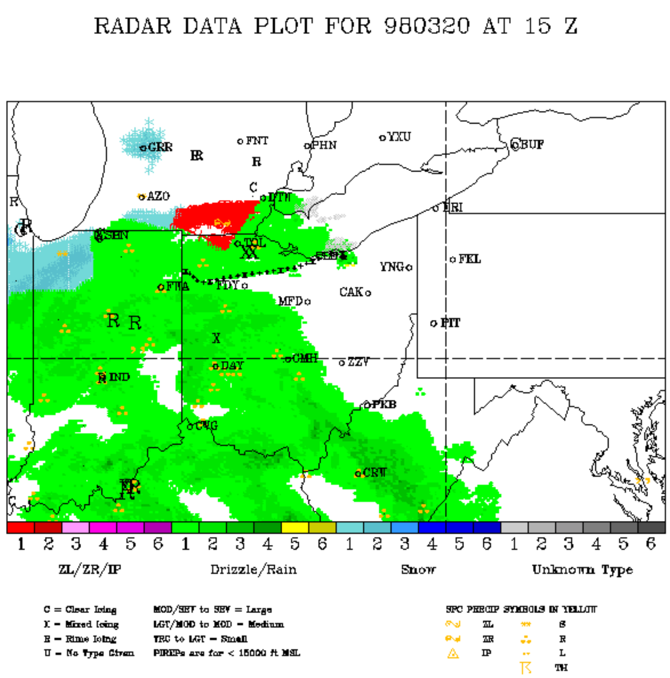
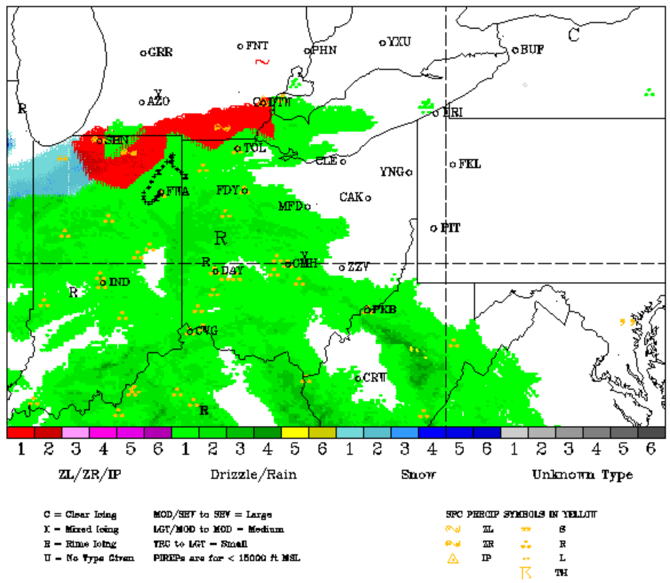


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980320, a) 1400 and b) 1500 UTC.

RADAR DATA PLOT FOR 980320 AT 16 Z



RADAR DATA PLOT FOR 980320 AT 17 Z

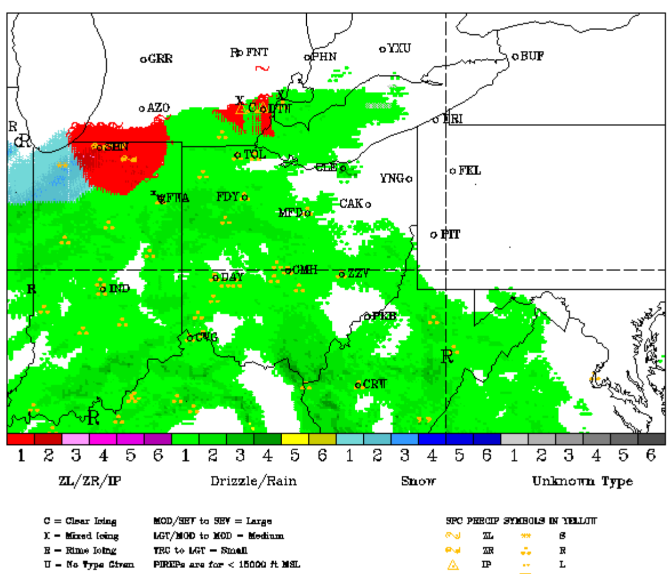
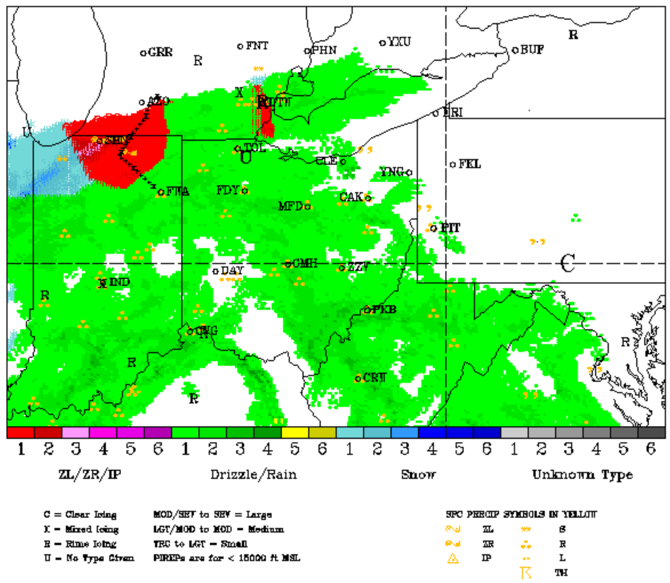


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980320, c) 1600 and d) 1700 UTC.

RADAR DATA PLOT FOR 980320 AT 18 Z



RADAR DATA PLOT FOR 980320 AT 19 Z

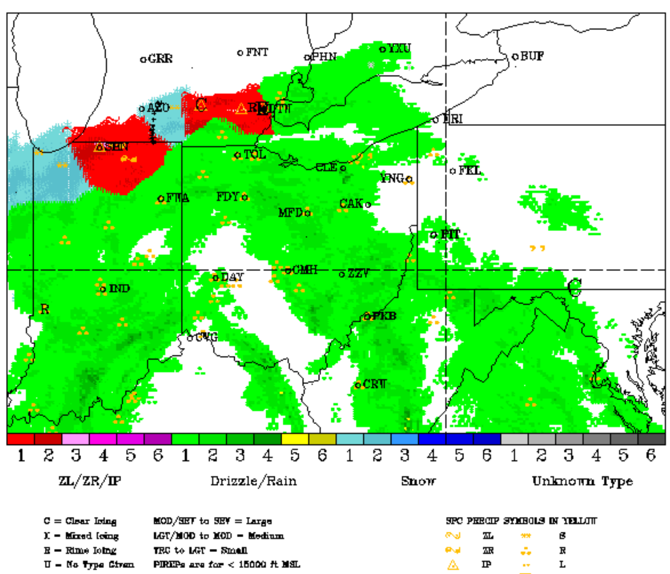
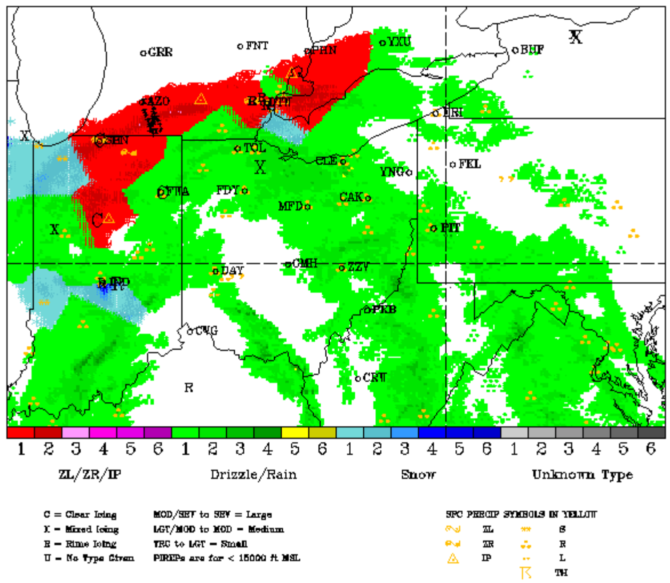


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980320, e) 1800 and f) 1900 UTC.

RADAR DATA PLOT FOR 980320 AT 20 Z



RADAR DATA PLOT FOR 980320 AT 21 Z

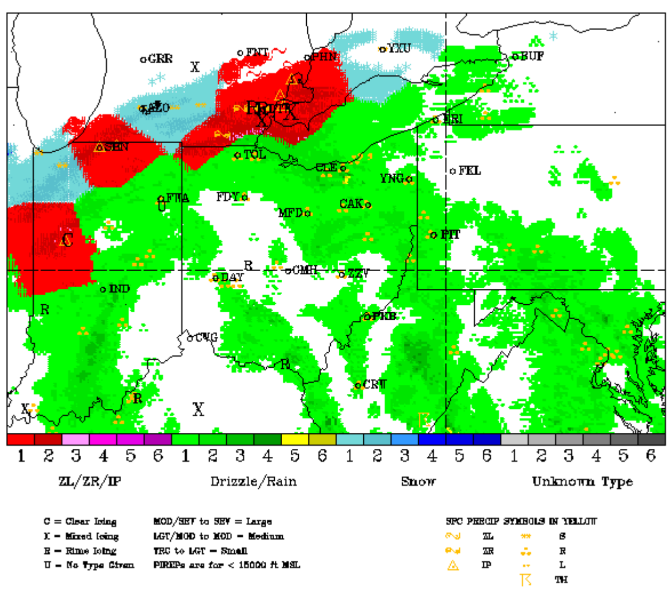
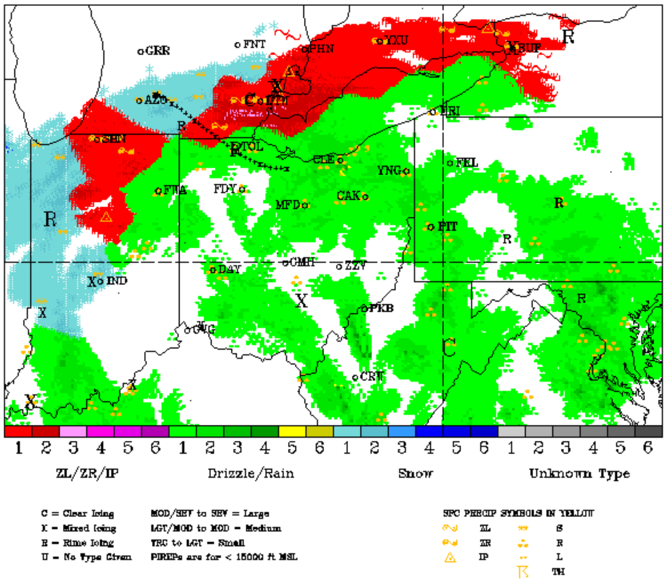


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980320, g) 2000 and h) 2100 UTC.

RADAR DATA PLOT FOR 980320 AT 22 Z



RADAR DATA PLOT FOR 980320 AT 23 Z

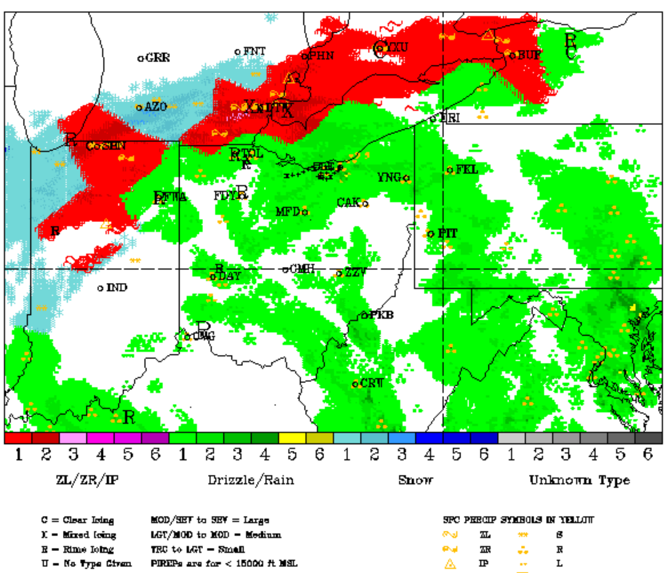
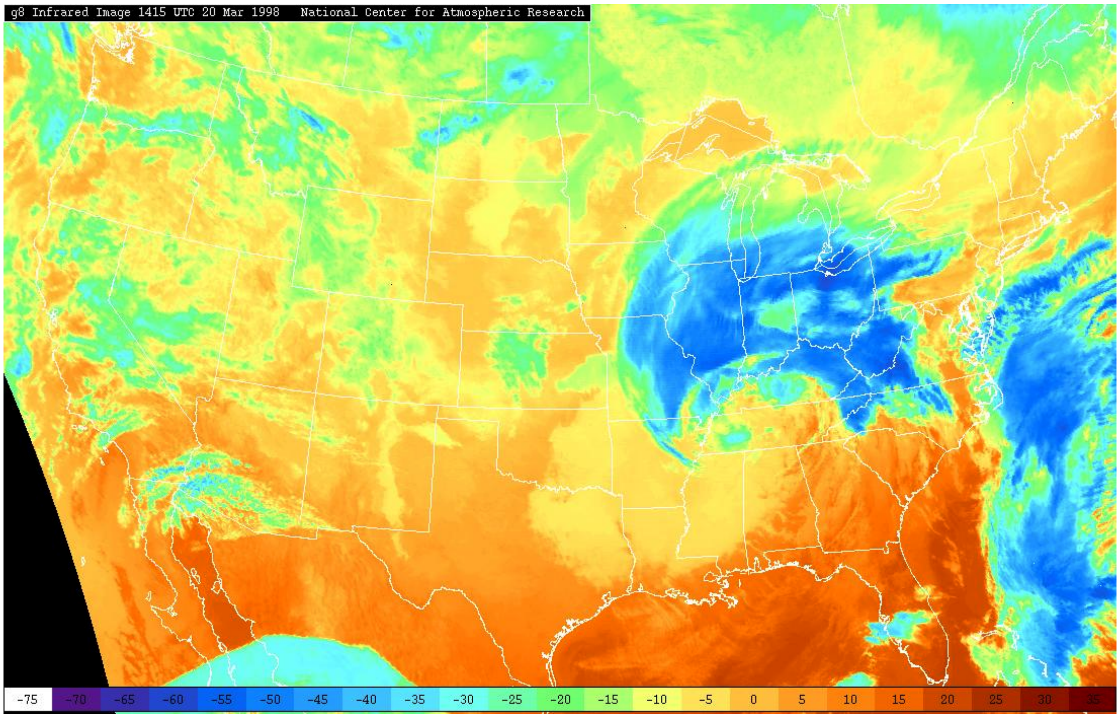


Figure 4 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980320, i) 2200 and j) 2300 UTC.



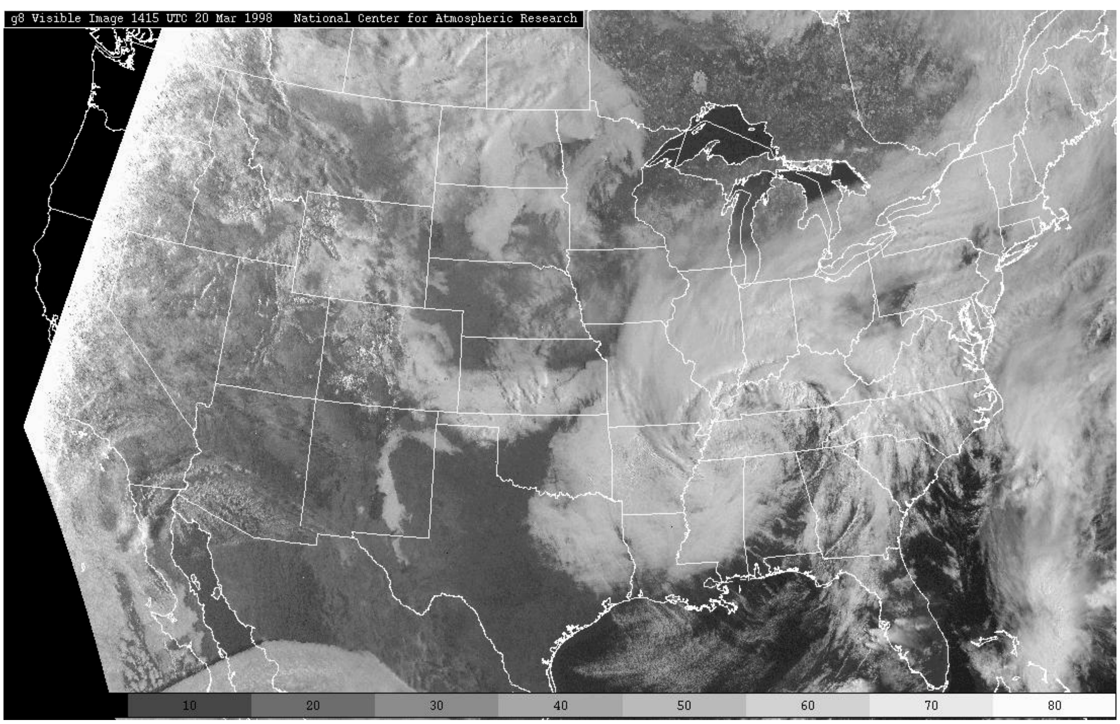


Figure 5 – GOES-8 a) infrared and b) visible satellite images for 980320, 1415 UTC.

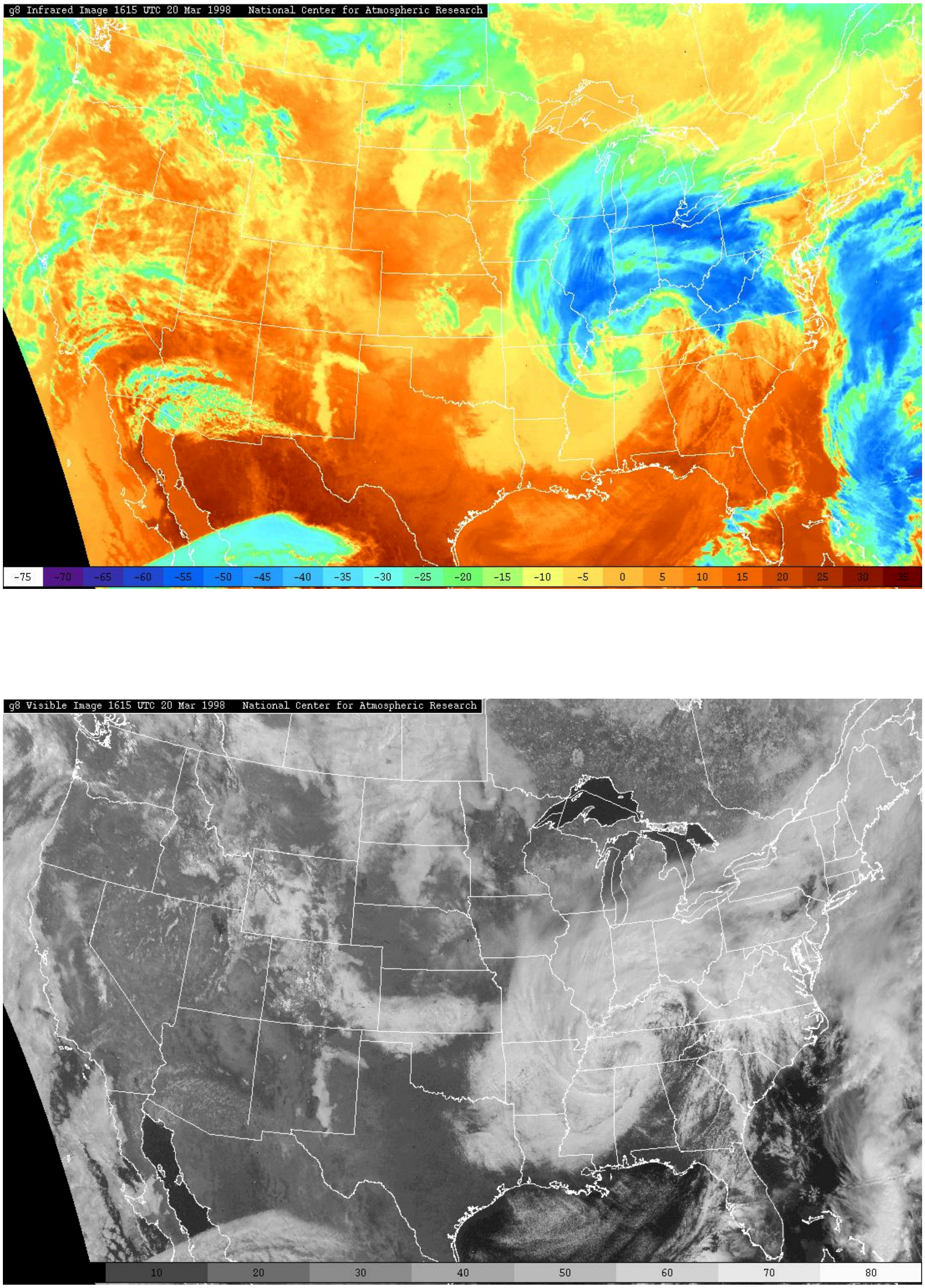
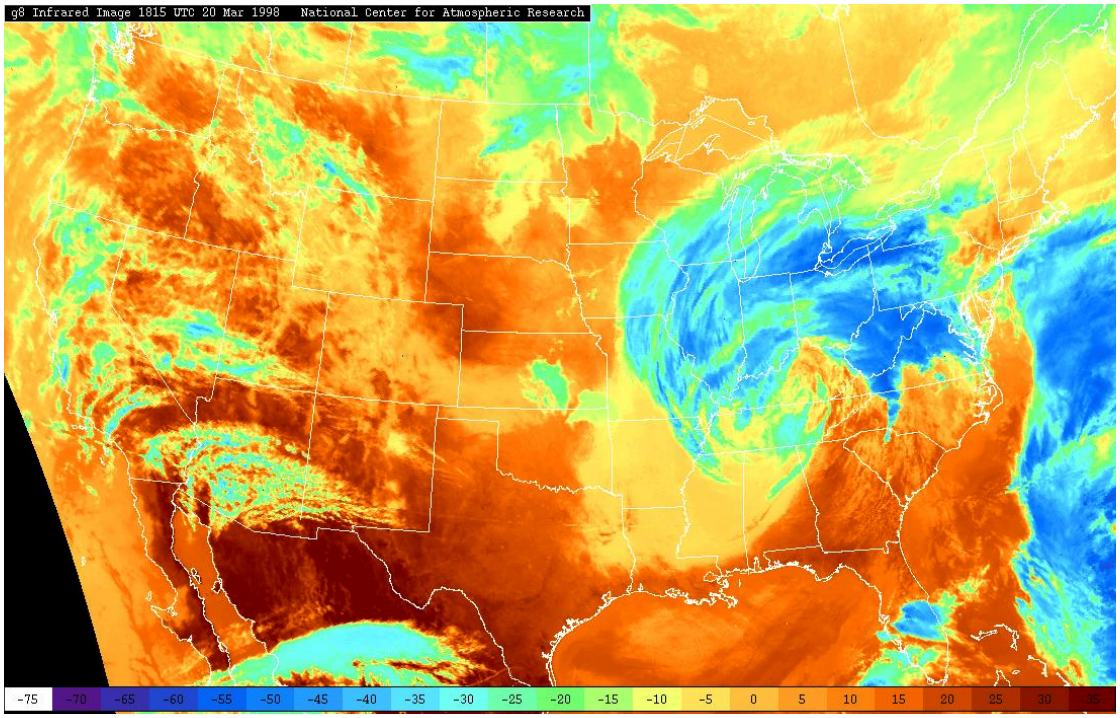


Figure 5 – GOES-8 c) infrared and d) visible satellite images for 980320, 1615 UTC.



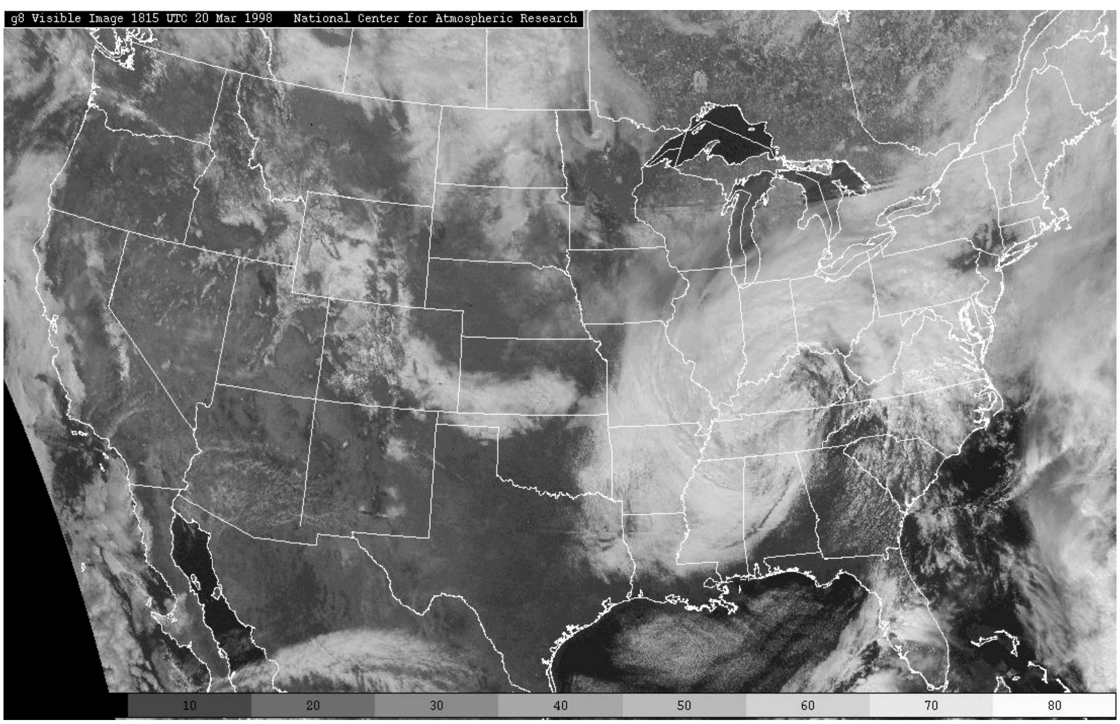
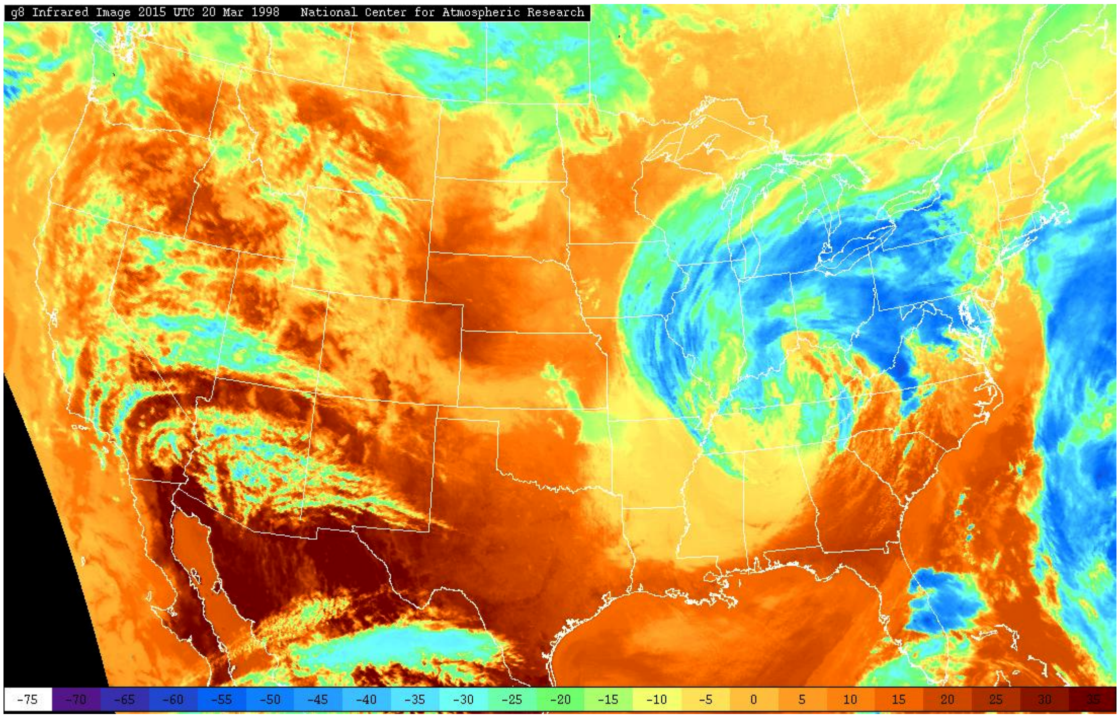


Figure 5 – GOES-8 e) infrared and f) visible satellite images for 980320, 1815 UTC.



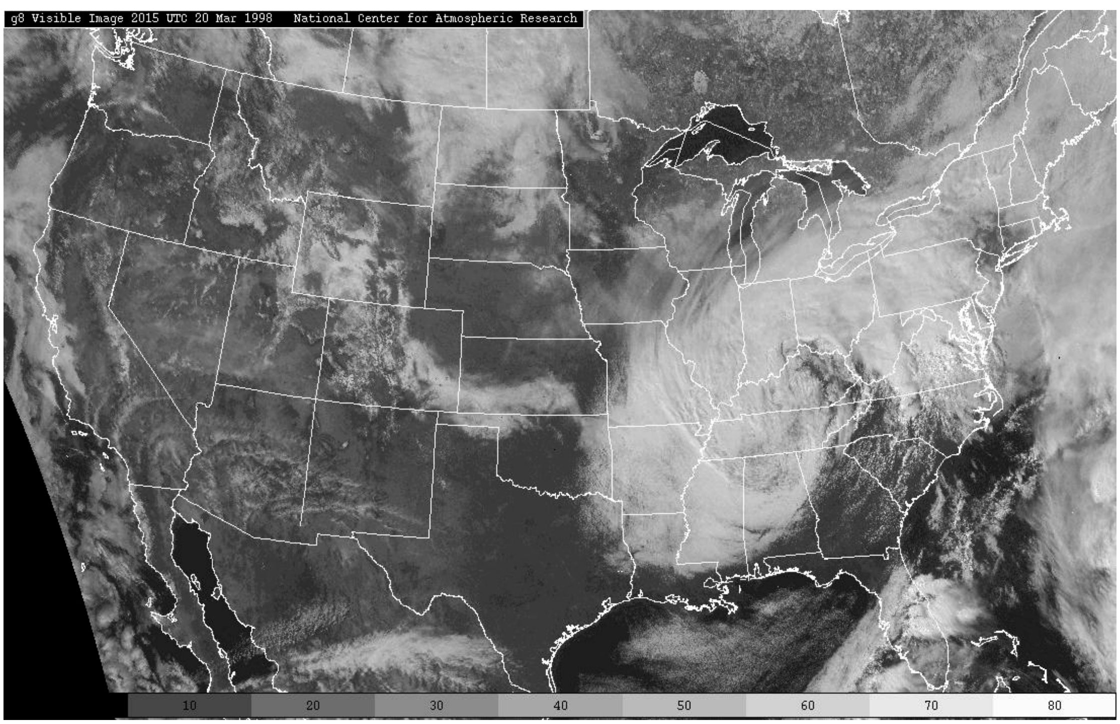
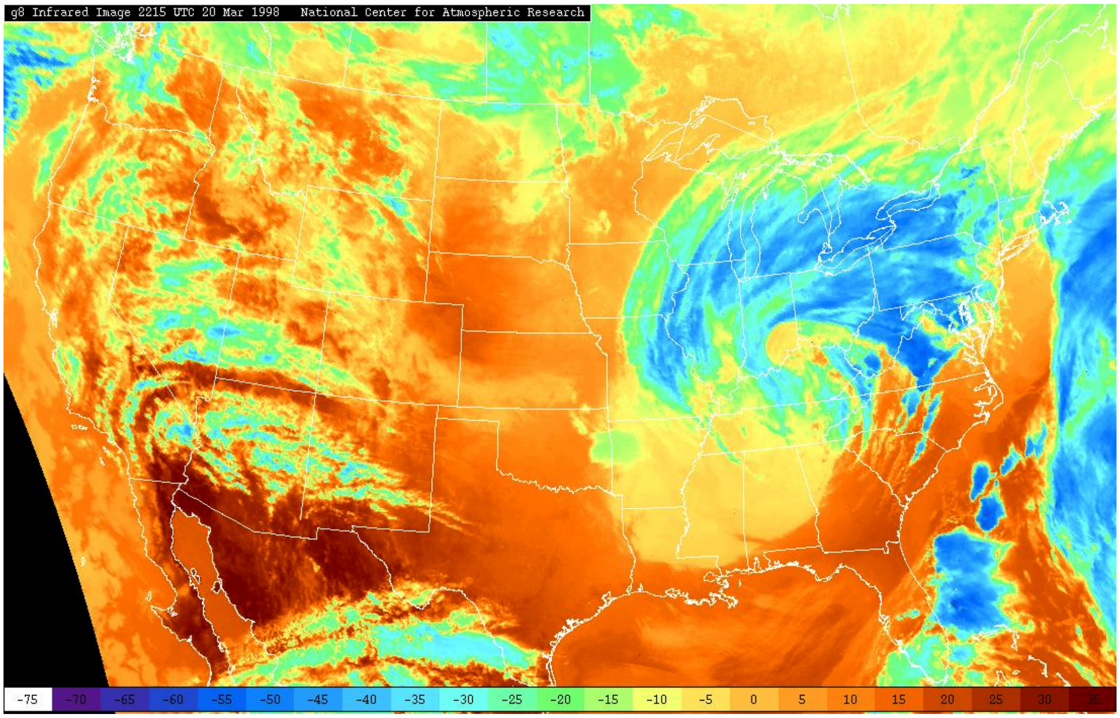


Figure 5 – GOES-8 g) infrared and h) visible satellite images for 980320, 2015 UTC.



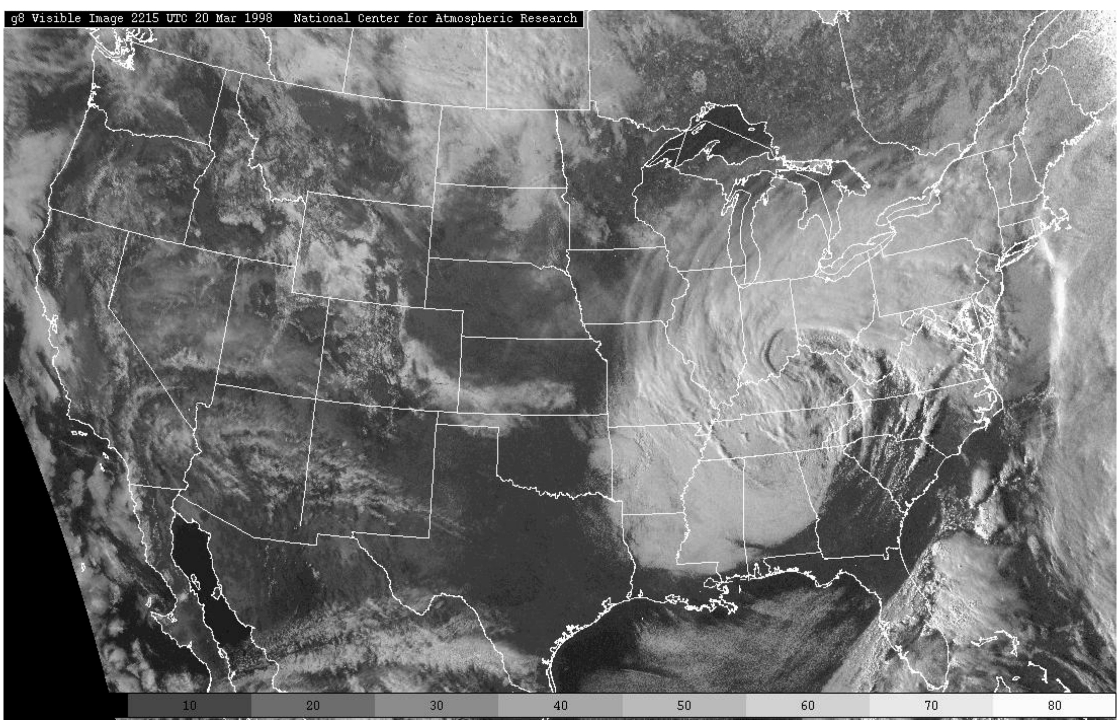
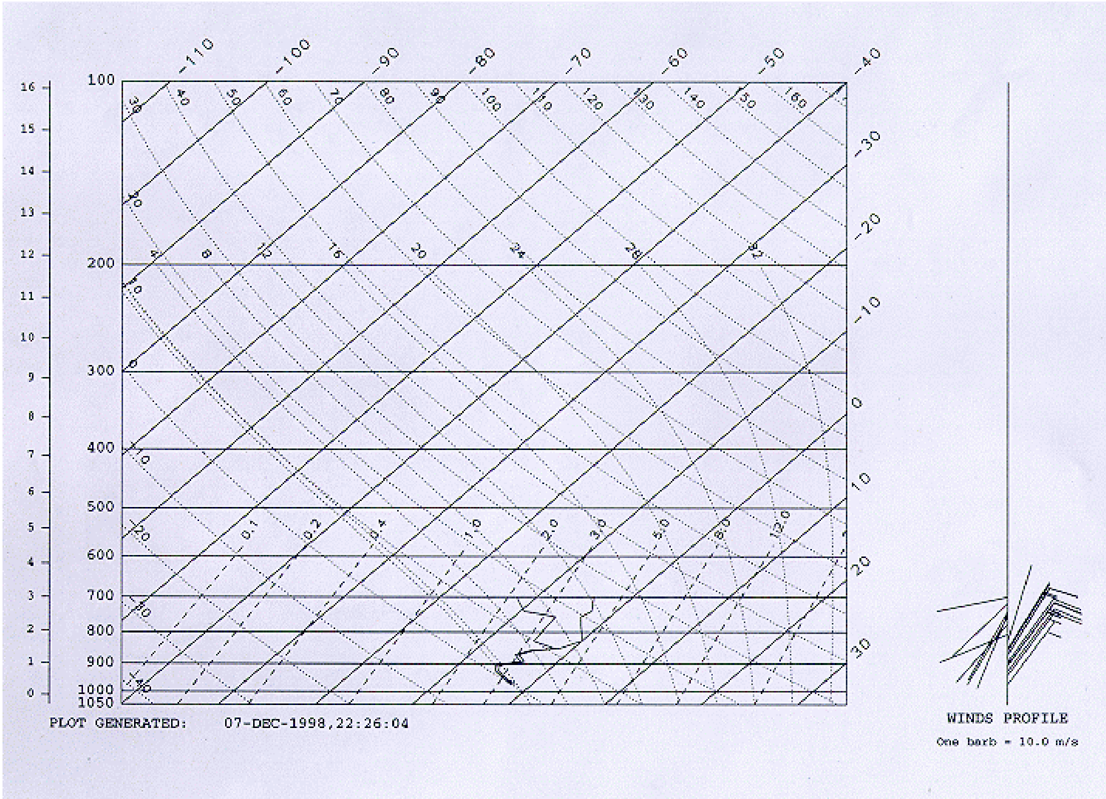


Figure 5 – GOES-8 i) infrared and j) visible satellite images for 980320, 2215 UTC.



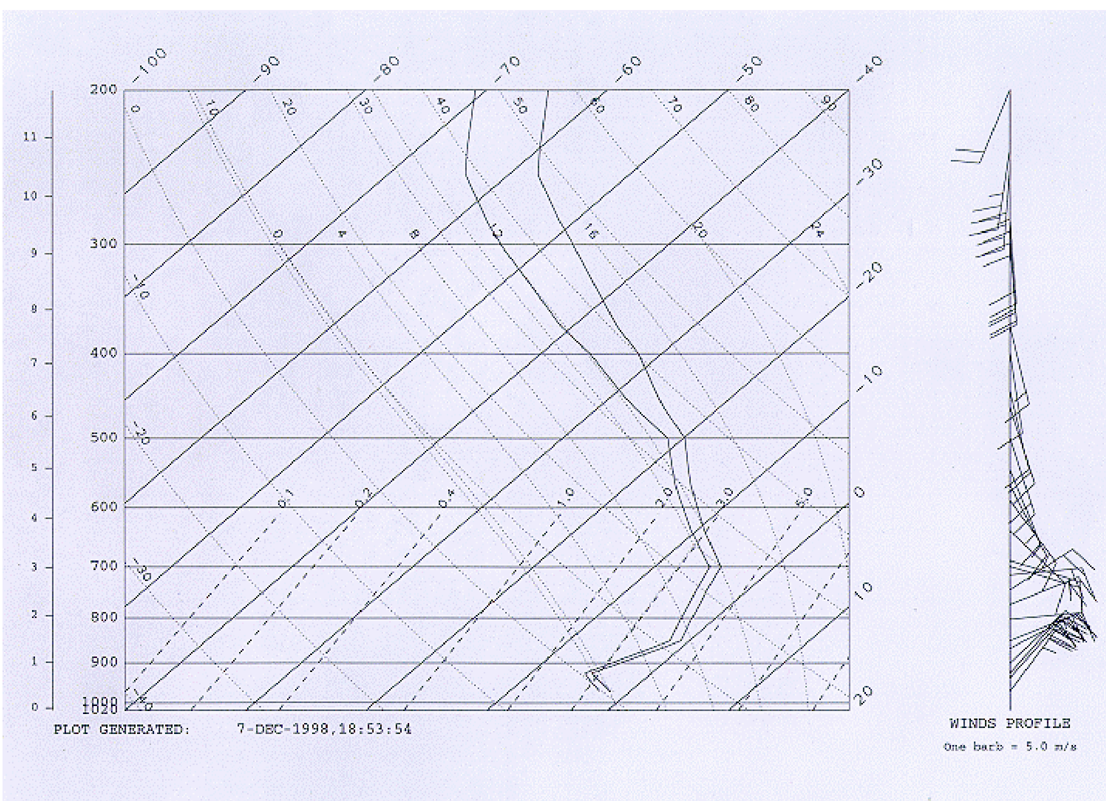
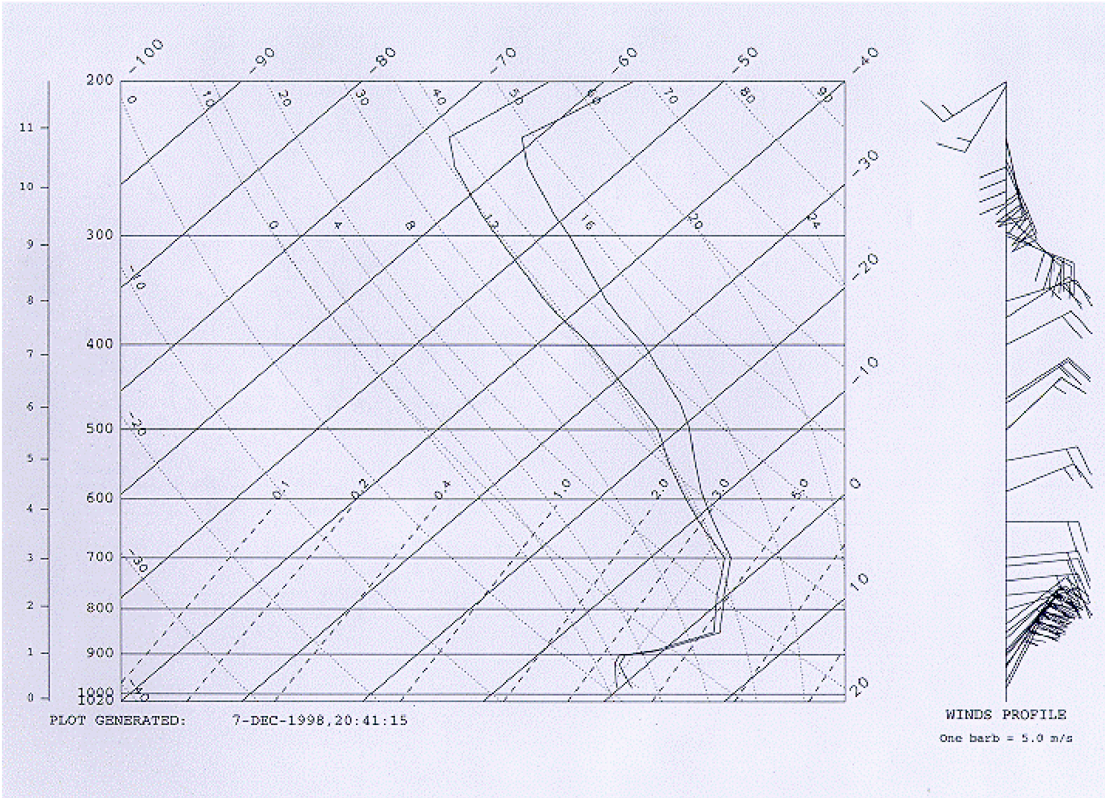


Figure 6 – Balloon-borne soundings from Detroit at a) 980320, 1200 and b) 980321, 0000 UTC.



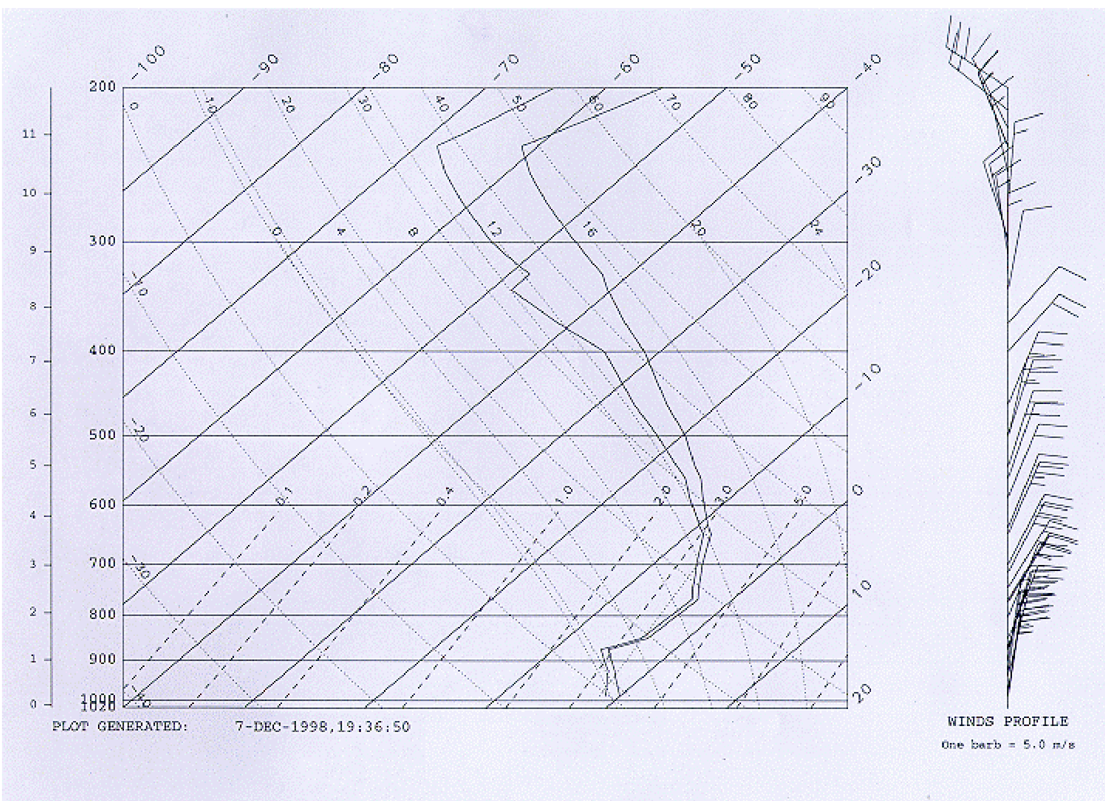


Figure 6 – Balloon-borne soundings from Lincoln IL at c) 980320, 1200 and d) 980321, 0000 UTC.

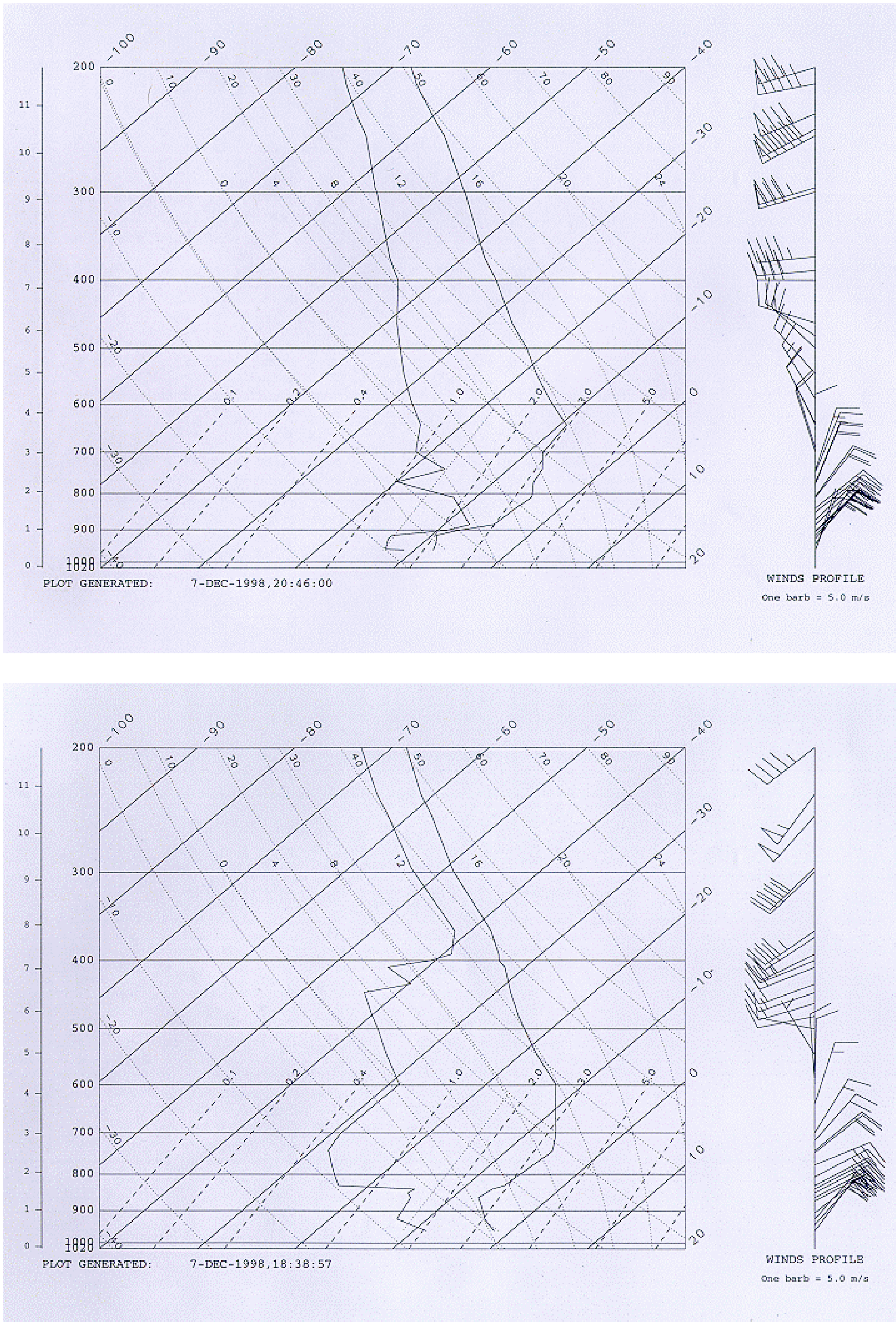
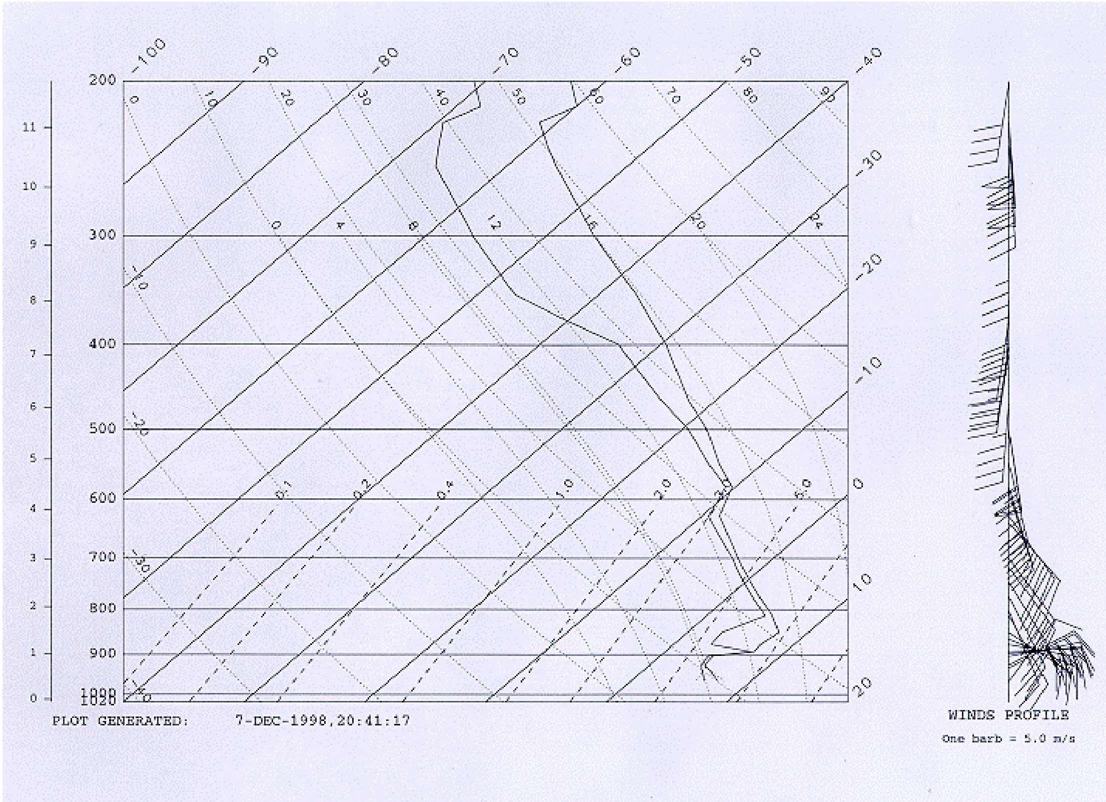


Figure 6 – Balloon-borne soundings from Alpena MI at e) 980320, 1200 and f) 980321, 0000 UTC.



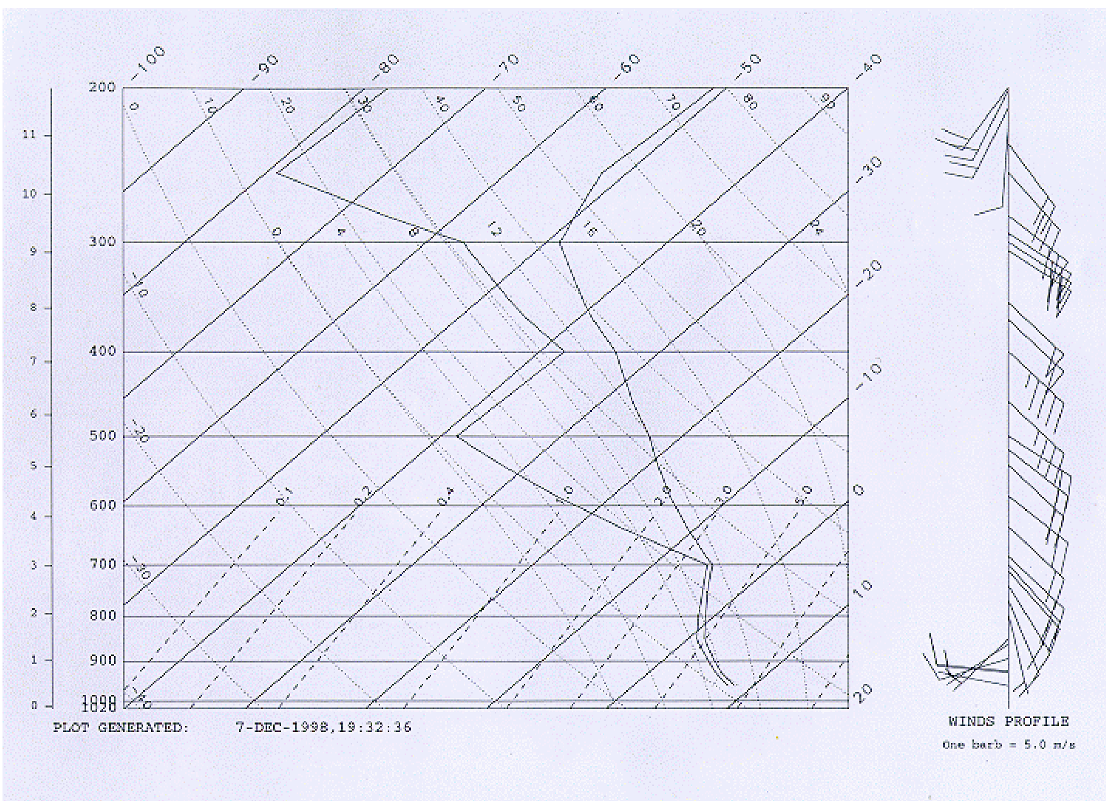
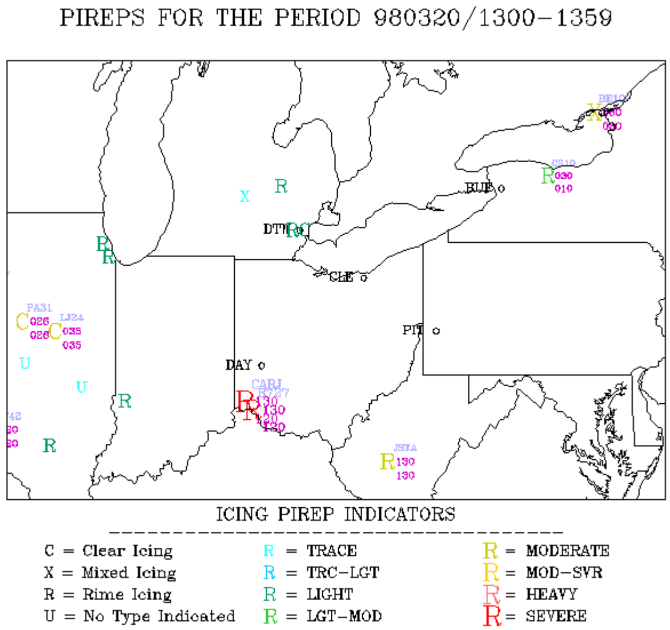


Figure 6 – Balloon-borne soundings from Wilmington at g) 980320, 1200 and h) 980321, 0000 UTC.



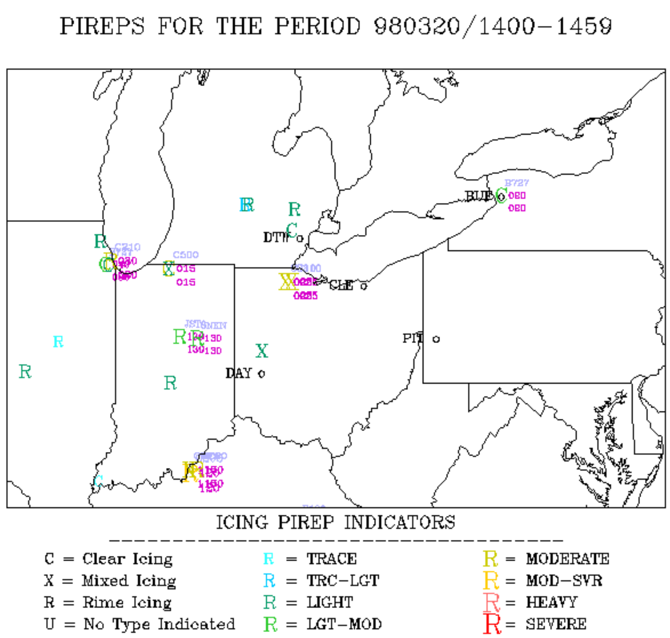
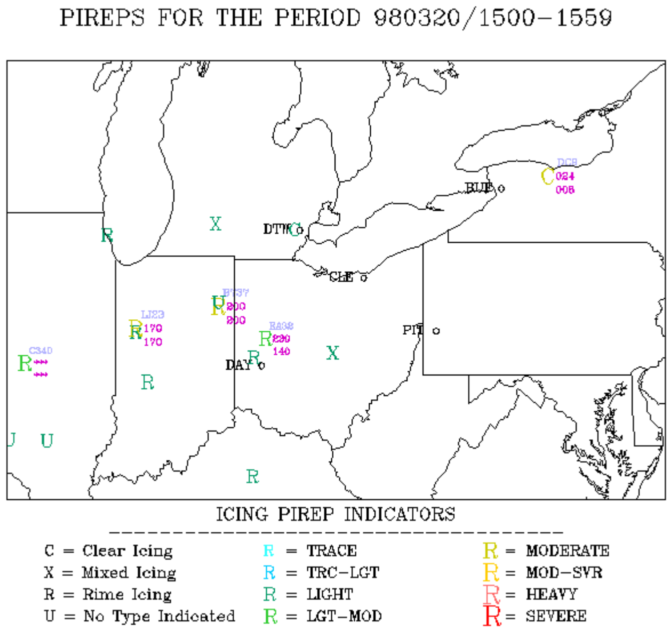


Figure 7 – Pilot reports of icing for 980320, a) 1300-1359 and b) 1400-1459 UTC.



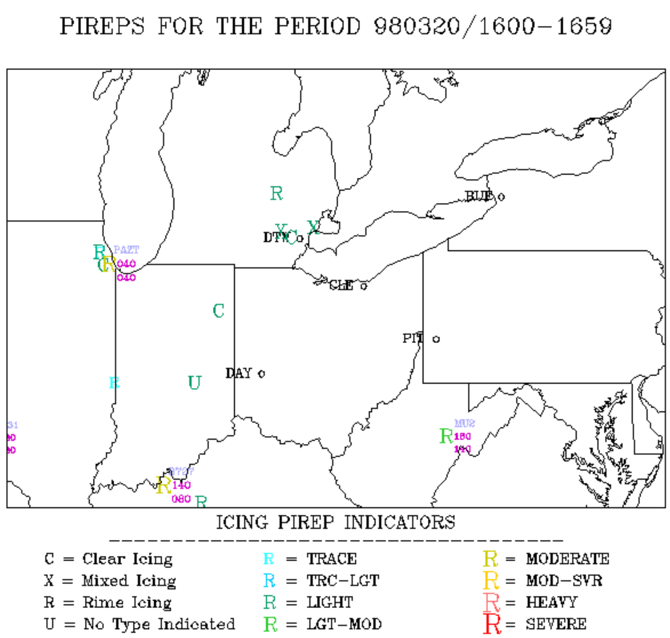
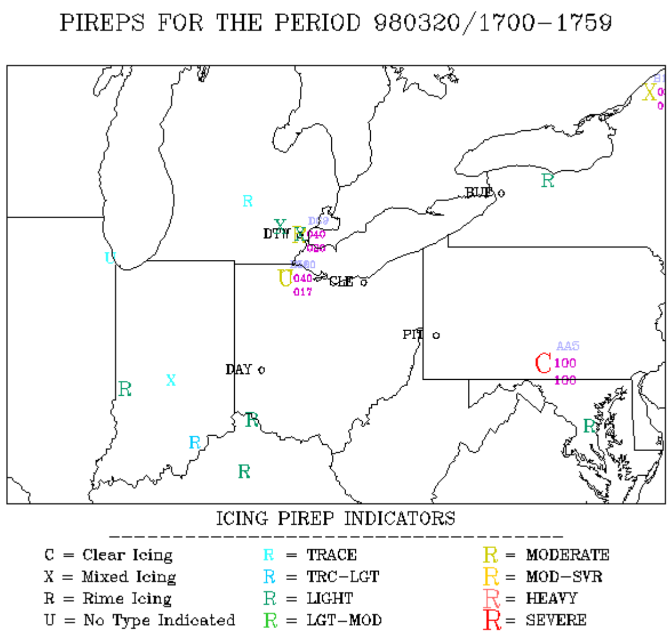


Figure 7 – Pilot reports of icing for 980320, c) 1500-1559 and d) 1600-1659 UTC.



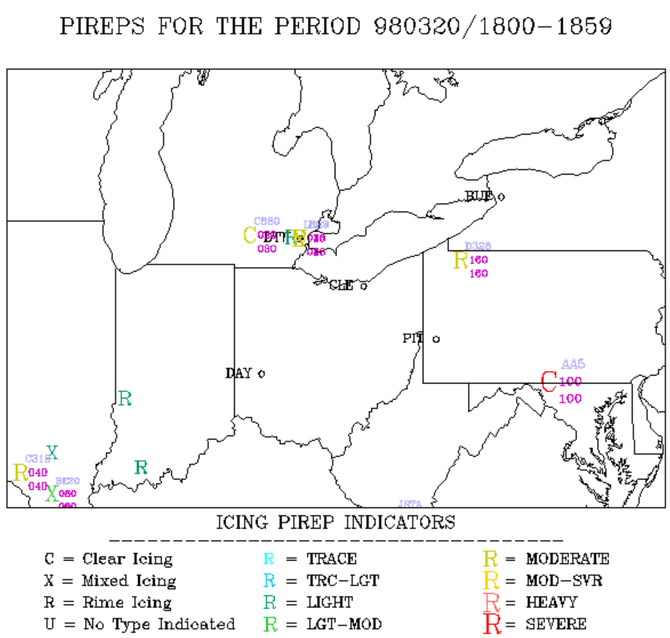
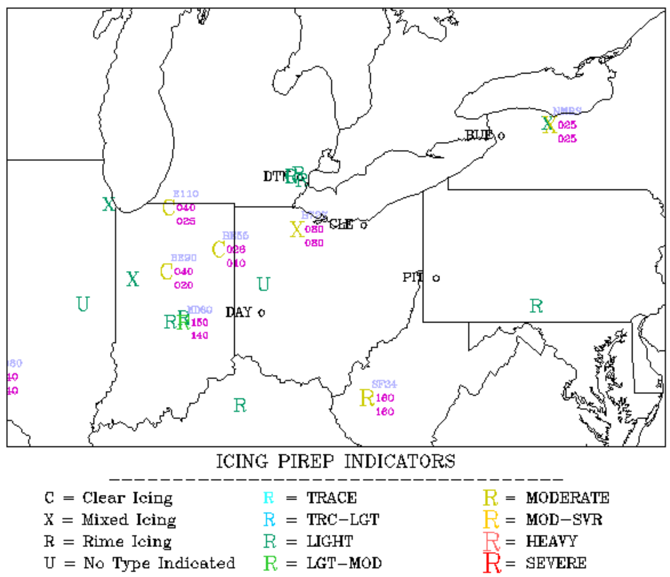


Figure 7 – Pilot reports of icing for 980320, e) 1700-1759 and f) 1800-1859 UTC.

PIREPS FOR THE PERIOD 980320/1900-1959



PIREPS FOR THE PERIOD 980320/2000-2059

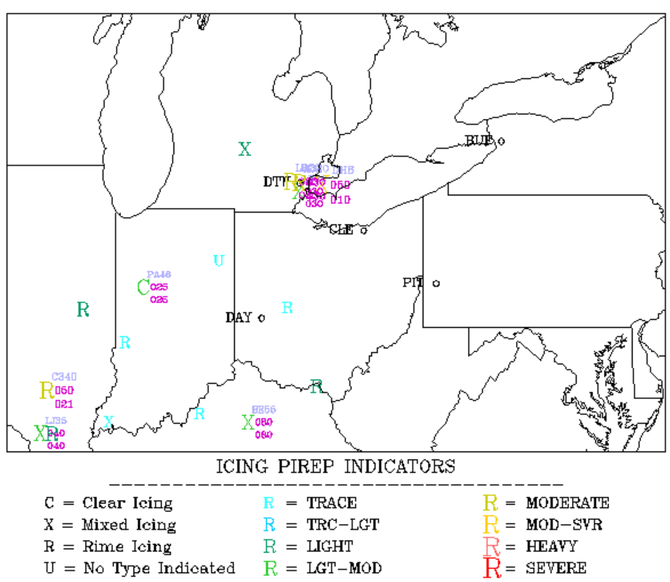
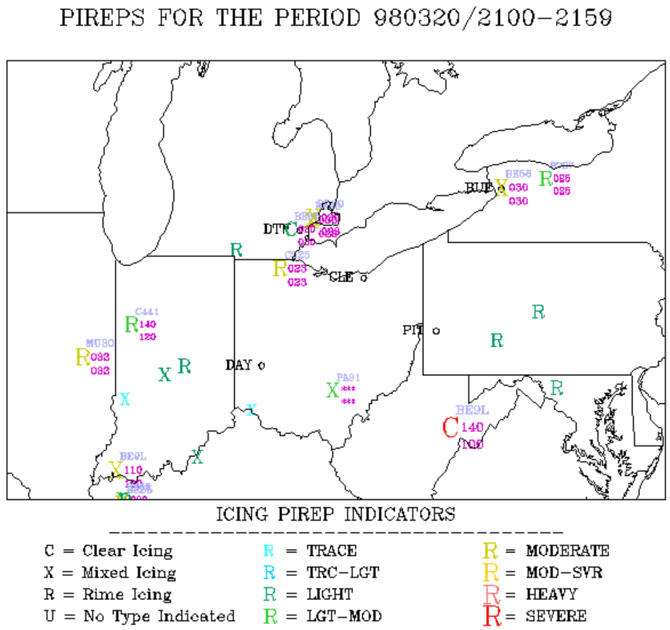


Figure 7 – Pilot reports of icing for 980320, g) 1900-1959 and h) 2000-2059 UTC.



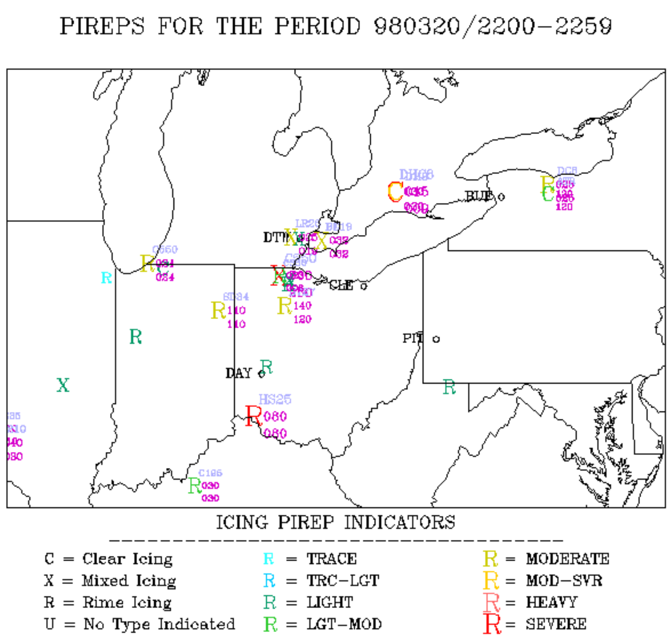


Figure 7 – Pilot reports of icing for 980320, i) 2100-2159 and j) 2200-2259 UTC.

March 25, 1998

Flight #1—Over Dayton and Columbus, OH, from 1442 to 1634 UTC.
Flight #2—Over Columbus and Mansfield, OH, from 1905 to 2009 UTC.

Brief overview

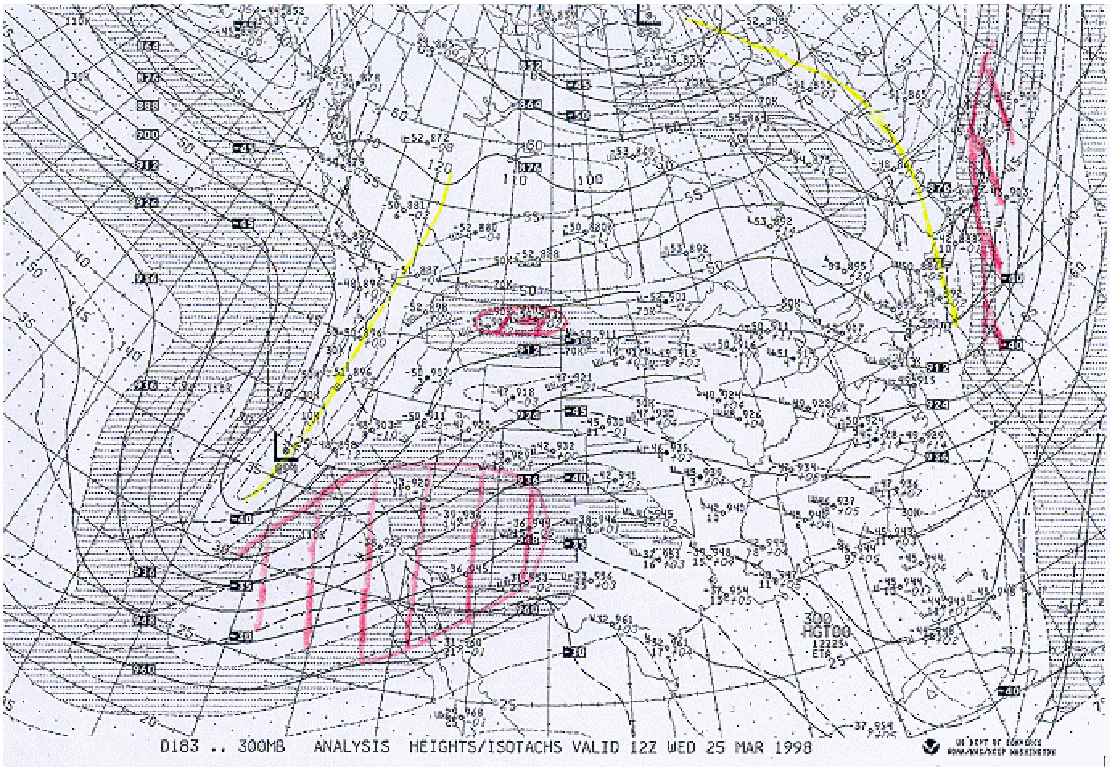
On this day, two flights were made into cloud droplets, supercooled and warm (T > 0C) drizzle, ice crystals, and mixtures thereof. During the first flight, the aircraft initially climbed through a thin cloud containing small droplets and some ice crystals at 10,600', a second, similar cloud deck with its base at 12,200 feet, and ice crystals in-between. These clouds contained LWC of 0.05 and 0.15, and were at temperatures of –8C and –9.5C, respectively. Higher LWC (0.3), as well as some freezing drizzle and warm drizzle was found near Findlay within and below all-water clouds that extended from 6500' and 9100'. Cloud top temperatures were only –3C, and the freezing level was at 7000'. More drizzle and warm (T > -3C) freezing drizzle was found near Dayton, but ice crystals became mixed into the cloud at times. After landing at Columbus, more drizzle (but no freezing drizzle) was found around 7000' during the climbout phase of the second flight. A bit more drizzle existed over Mansfield within clouds that had CTTs of about –1C.

Relevant weather features

A rather dull pattern was in place across the region at 1200 UTC (Fig. 1). Deep, warm advection was present at all levels, with winds veering from southwesterly at 850 mb to northwesterly at 500mb. No trough axes or lows were found nearby. Moisture was present across all but eastern Ohio at 500 mb. The same was true at 700 mb, except for a swath of dry air across the southern border of Michigan. Dry conditions at 850 mb covered eastern Ohio again, but were also present in eastern Michigan. At the surface (Fig. 2), the flow was from the south and southeast, thanks to a fairly strong west-to-east pressure gradient between a 1038 mb high over Delaware, and an elongated low/trough over the western High Plains. A weak warm front ran from South Dakota to Tennessee, where it became a stationary front over the Southeast. The warm front became better defined and moved northeastward to southern Indiana and central Kentucky by 2100 UTC. Patchy light rain that fell over southeast Indiana, north Kentucky, and southwest Ohio at 1400 UTC moved slowly eastward and fell apart to the southeast of Dayton (Fig. 3). The Twin Otter sampled the northern end of, and the clouds to the northeast of this precipitation.

Satellite data nicely mirror the progression of these clouds and precipitation (Fig. 4). Clouds with CTTs of –15C to –30C present near Cincinnati at 1415 UTC moved eastward, warmed, and broke up over the next six hours. Clouds with warmer tops (CTTs > -10C) were present on the fringes of the precipitation. The 1200 and 0000 UTC Wilmington soundings (Fig. 5) also show this progression, as skies containing deep clouds with CTTs near –30C changed to only have a thin cloud with a CTT of 0C

there. A similar progression occurred at Detroit, while conditions at Pittsburgh changed from rather dry to having a warm, liquid cloud deck (CTT = -4C) between 7000' and 10,000'. Mostly light rime icing was indicated within and along the fringes of the precipitation on this day (Fig. 6).



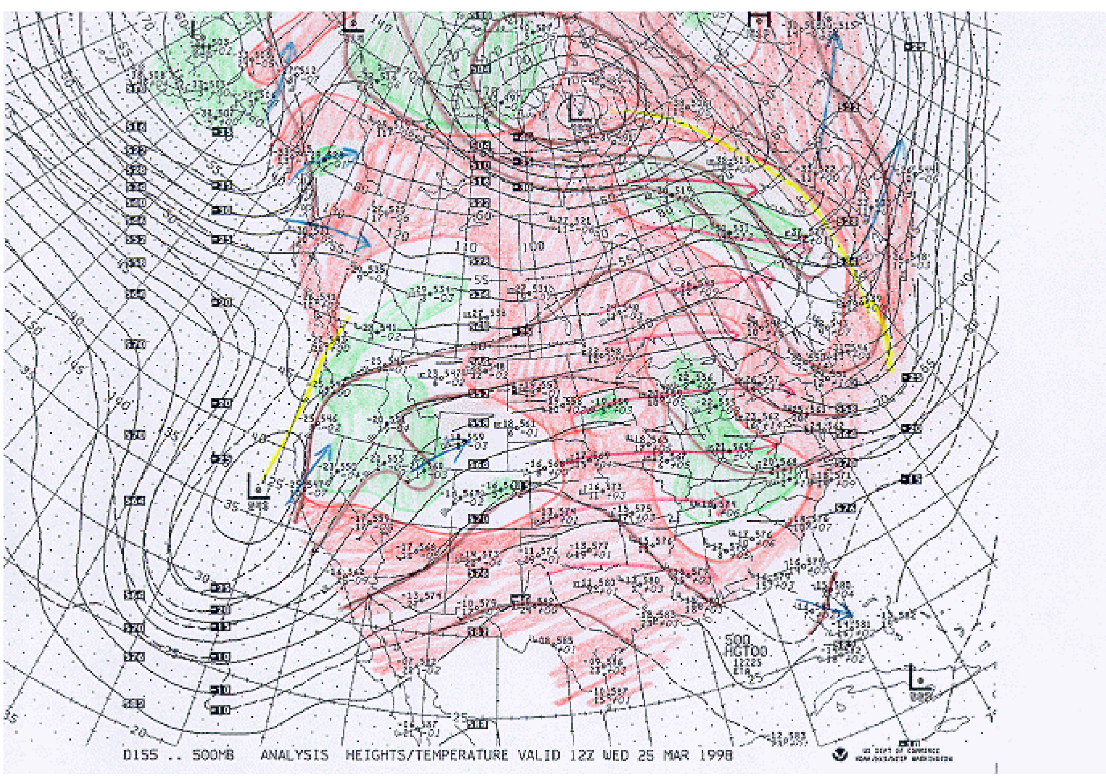


Figure 1 – Upper-air charts for 980325, 1200 UTC at a) 300 and b) 500 mb.

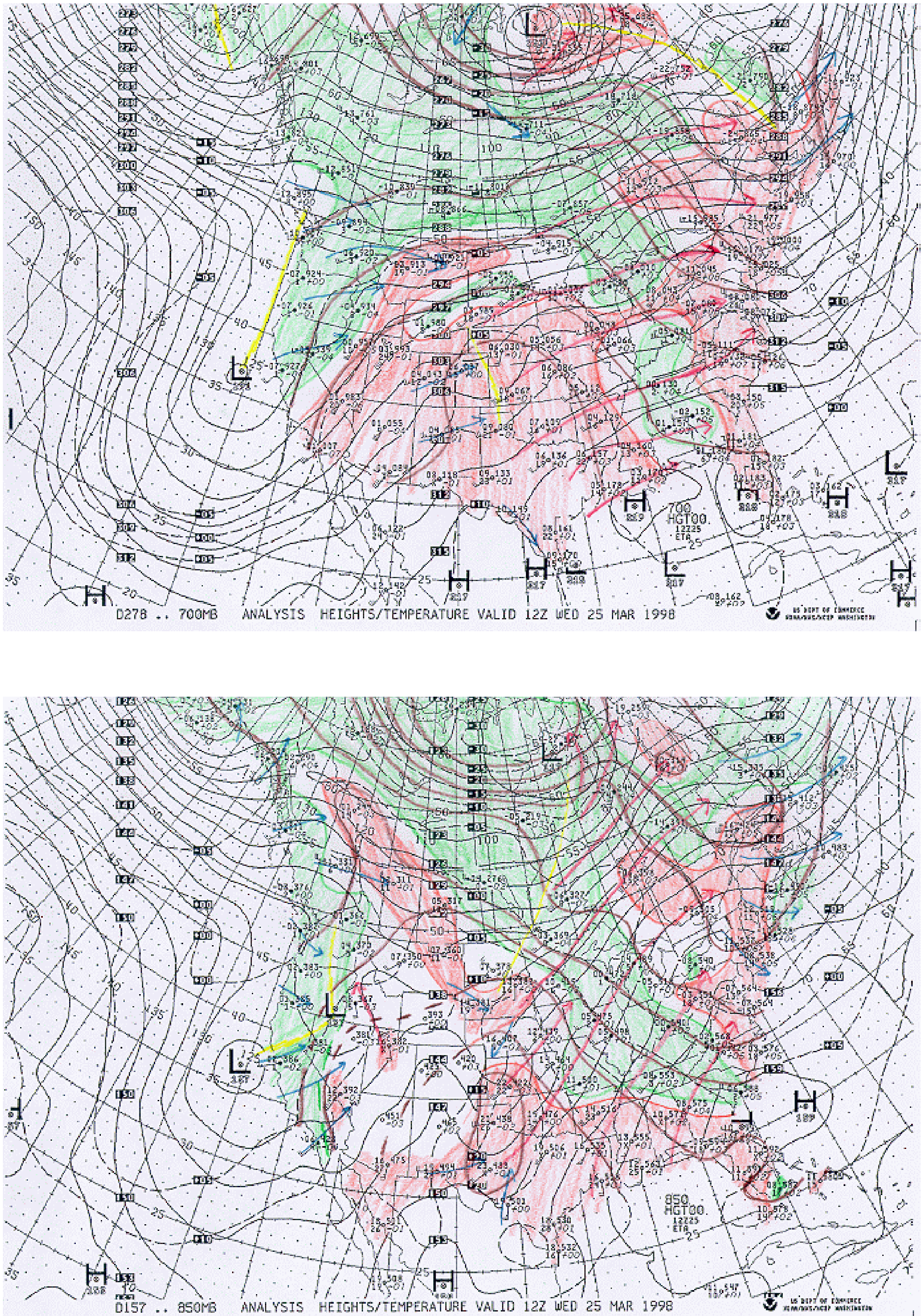


Figure 1 – Upper-air charts for 980325, 1200 UTC at c) 700 and d) 850 mb.

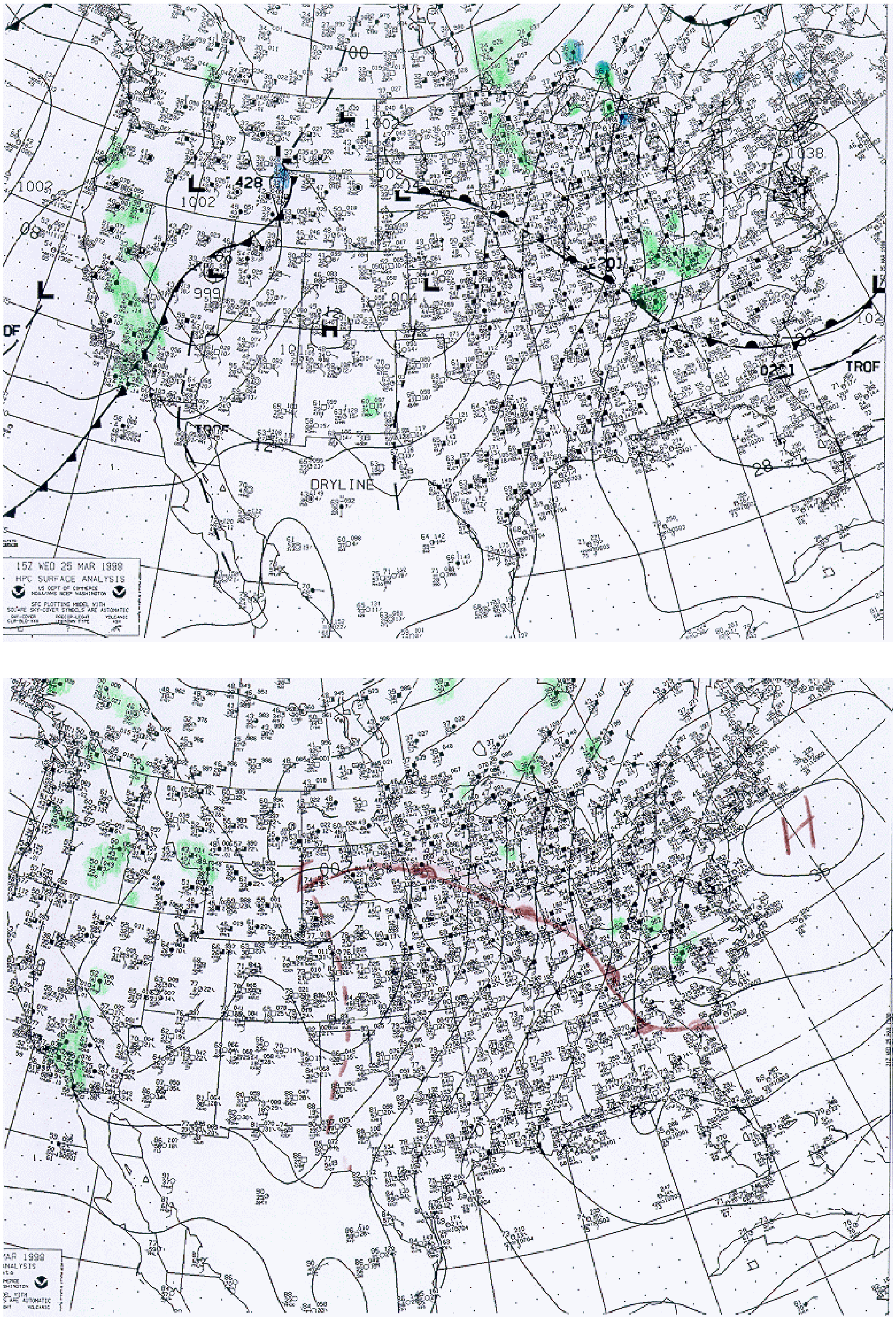


Figure 2 – Surface charts for 980325, a) 1500 and b) 2100 UTC.

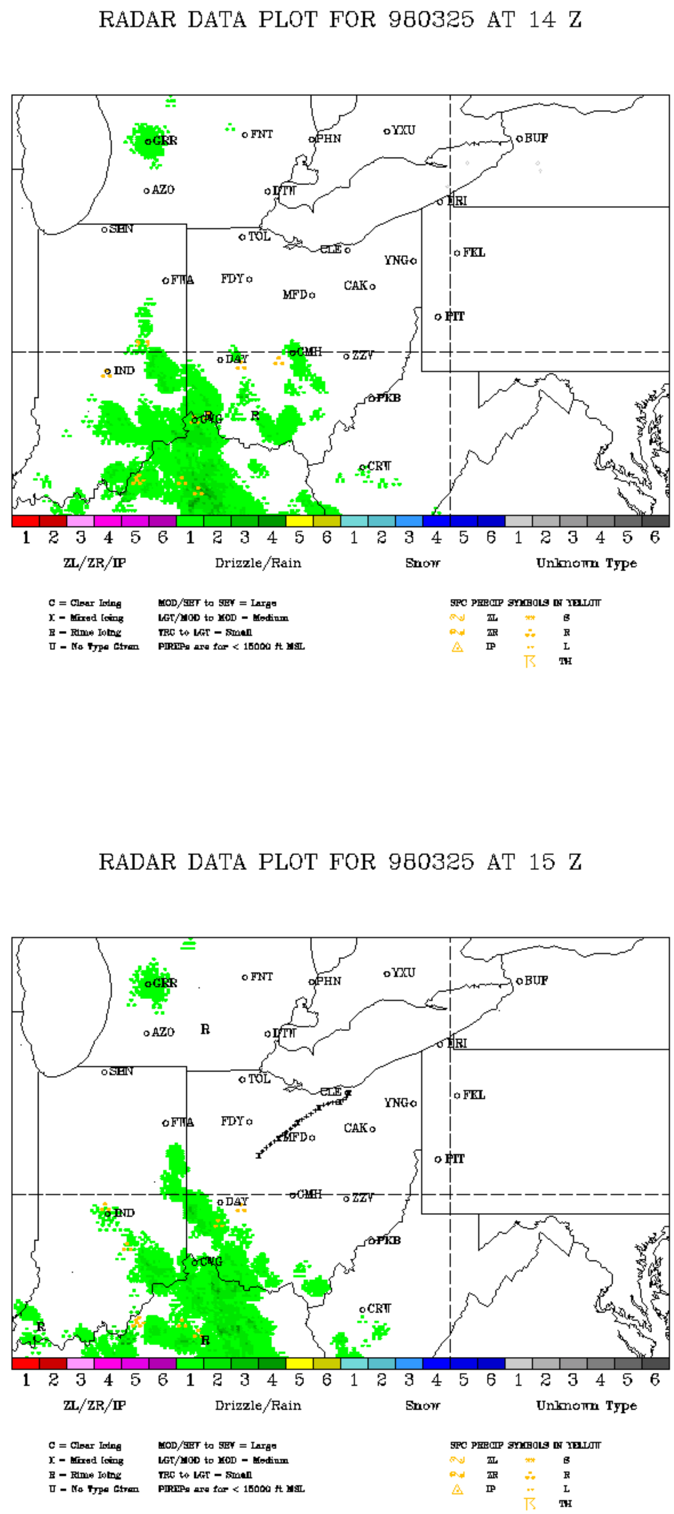
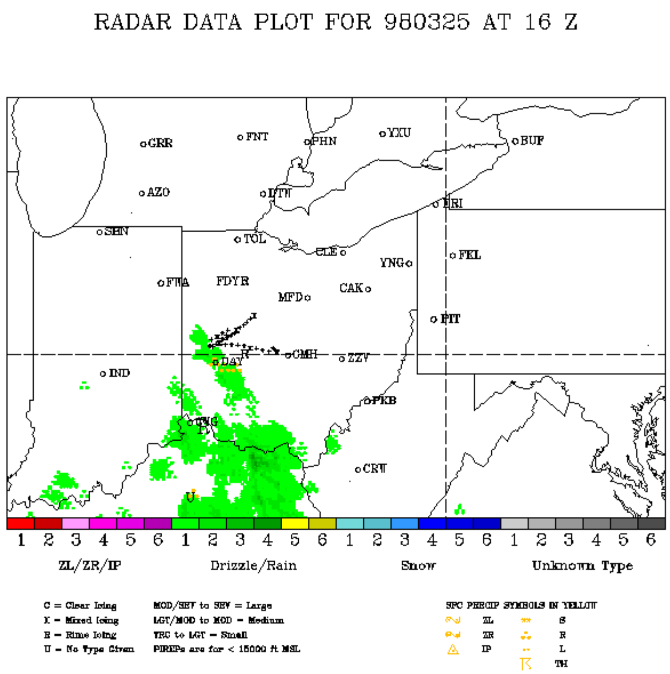


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980325, a) 1400 and b) 1500 UTC.



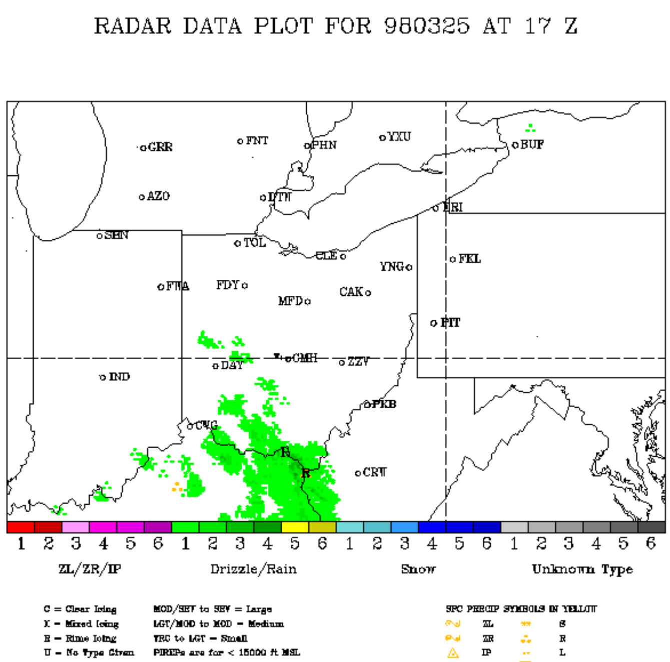
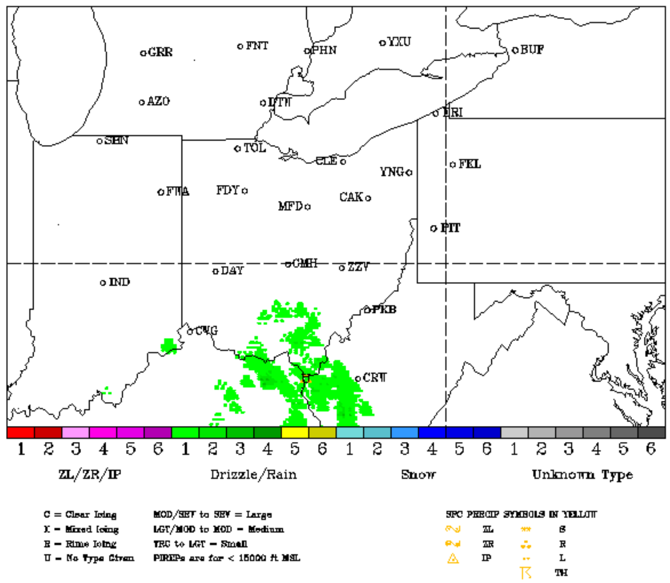


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980325, c) 1600 and d) 1700 UTC.

RADAR DATA PLOT FOR 980325 AT 18 Z



RADAR DATA PLOT FOR 980325 AT 19 Z

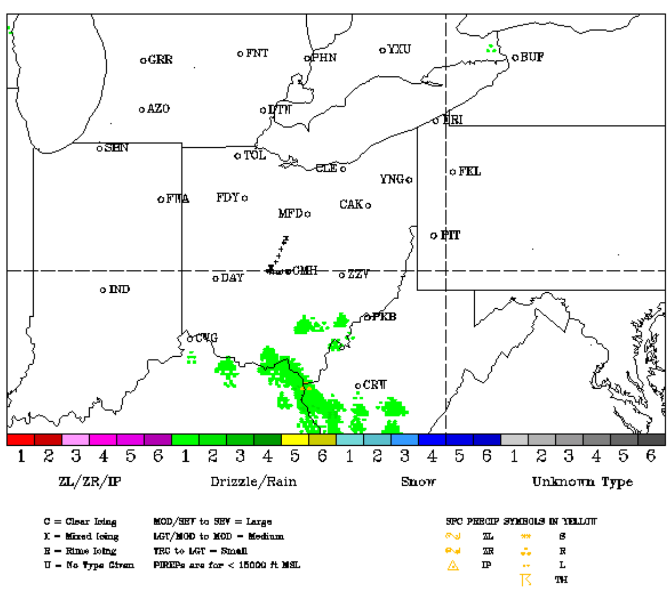
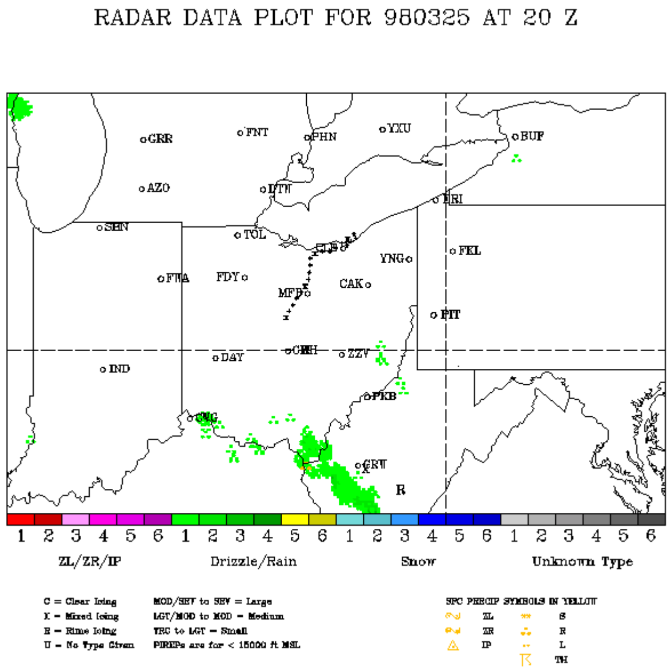


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980325, e) 1800 and f) 1900 UTC.



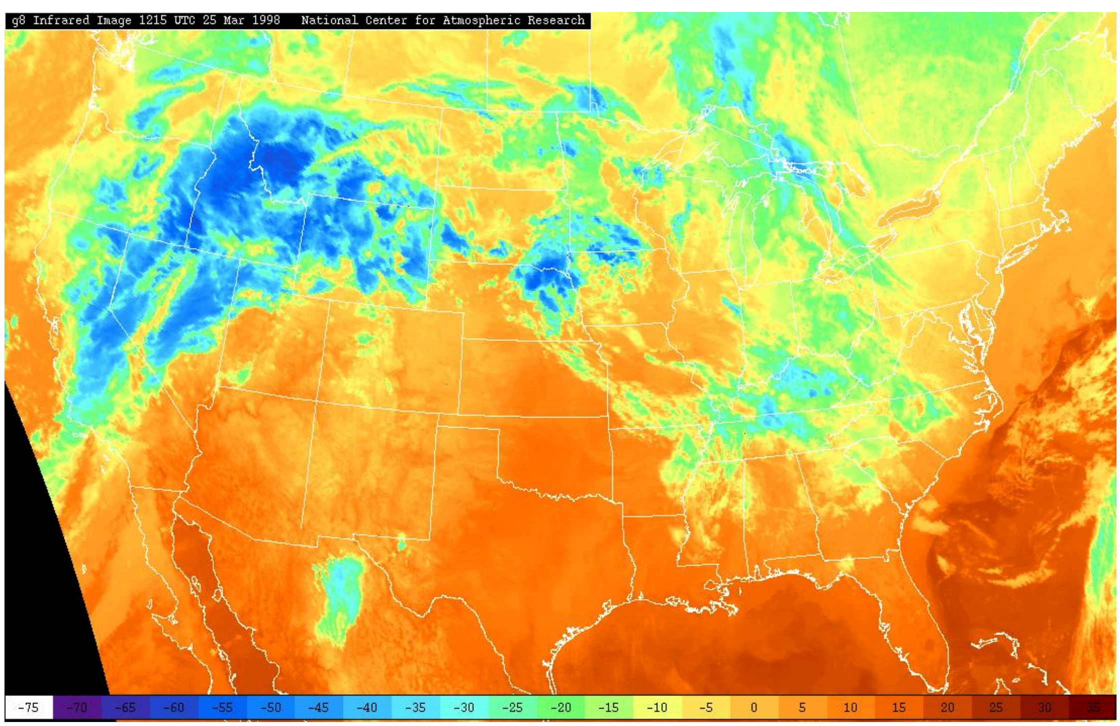
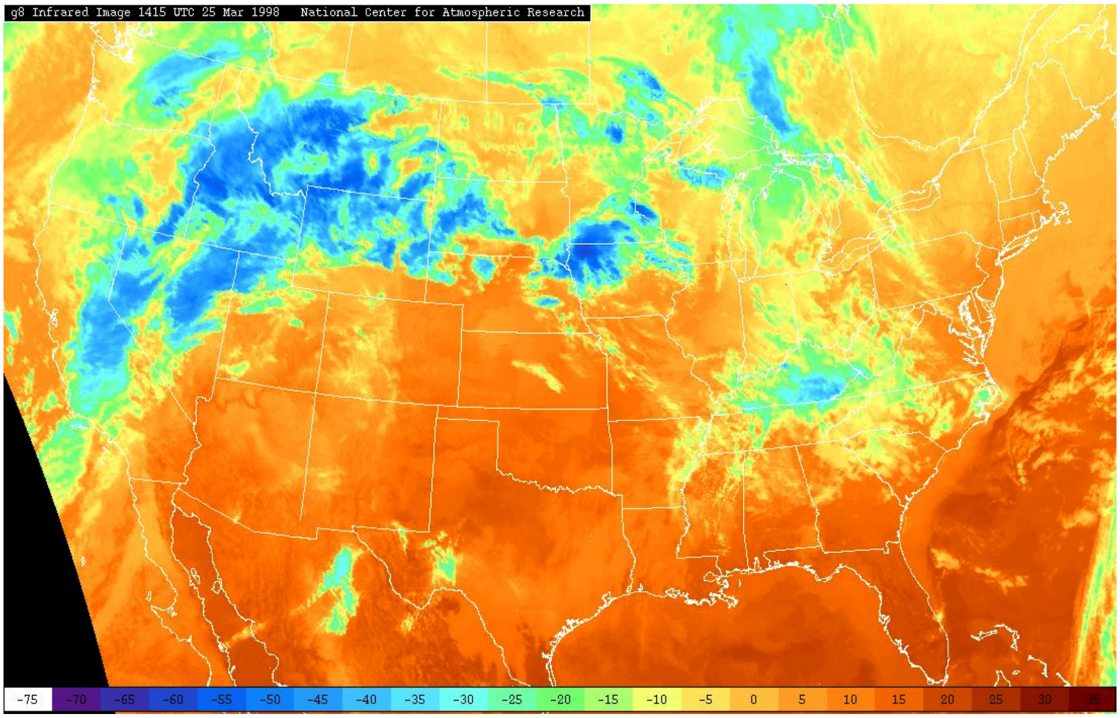


Figure 3 – Radar data, surface observations, icing PIREPs and Twin Otter tracks for 980325, g) 2000 UTC.
Figure 4 – GOES-8 a) infrared satellite image for 980325, 1215 UTC.



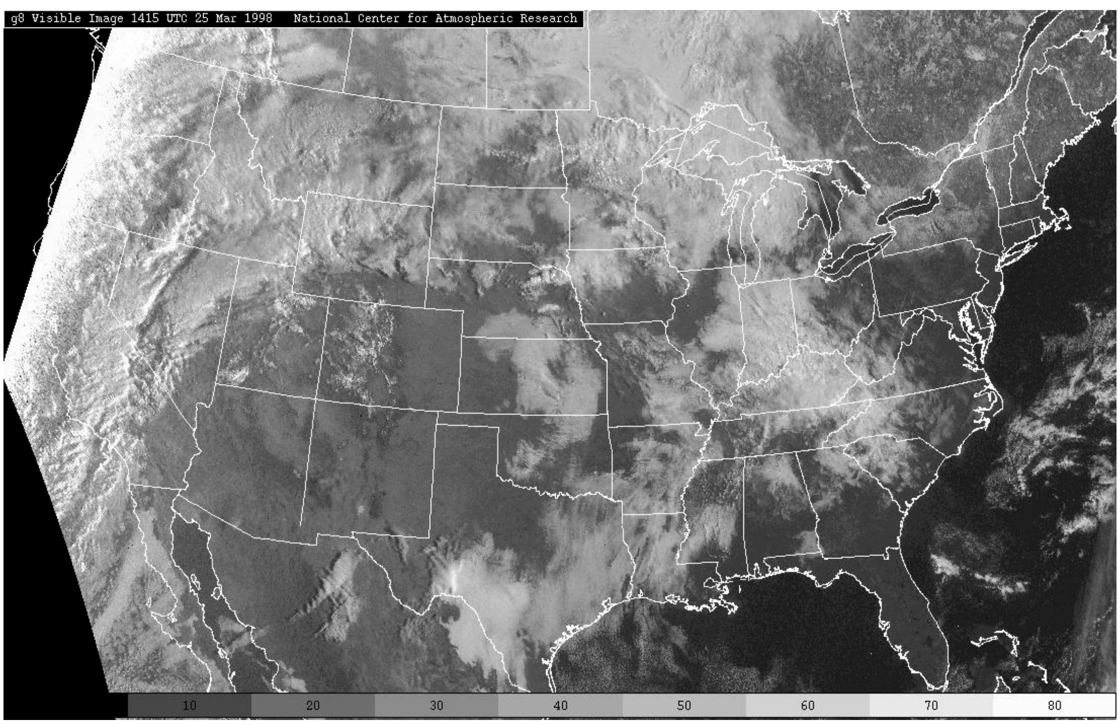
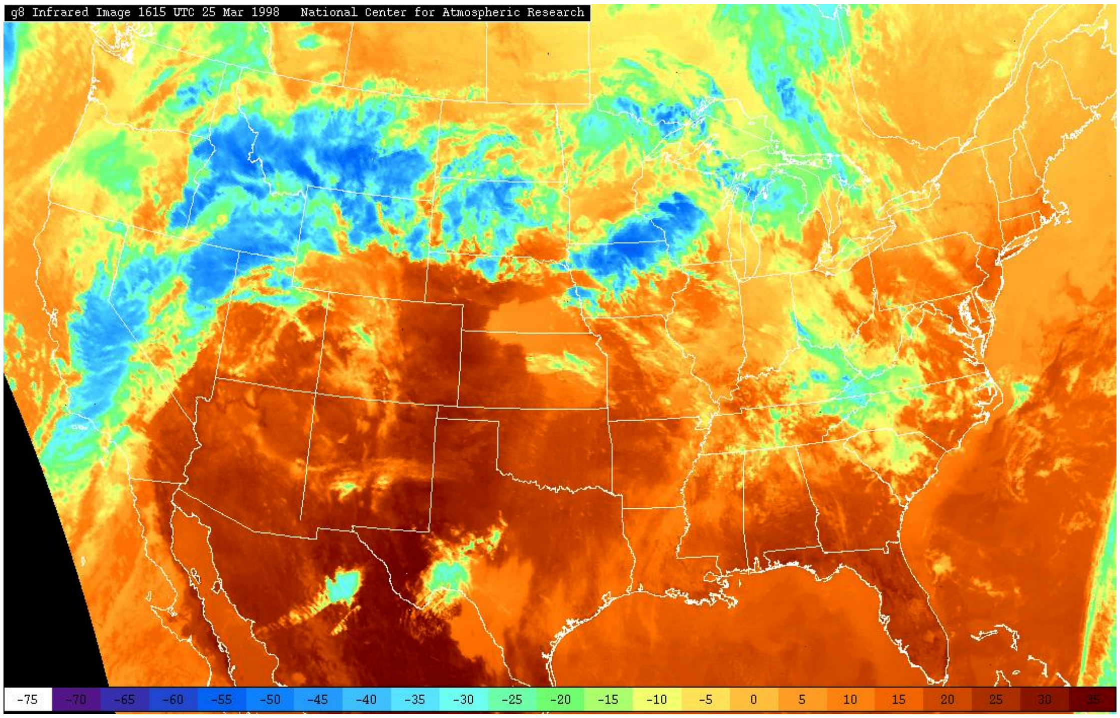


Figure 4 – GOES-8 b) infrared and c) visible satellite image for 980325, 1415 UTC.



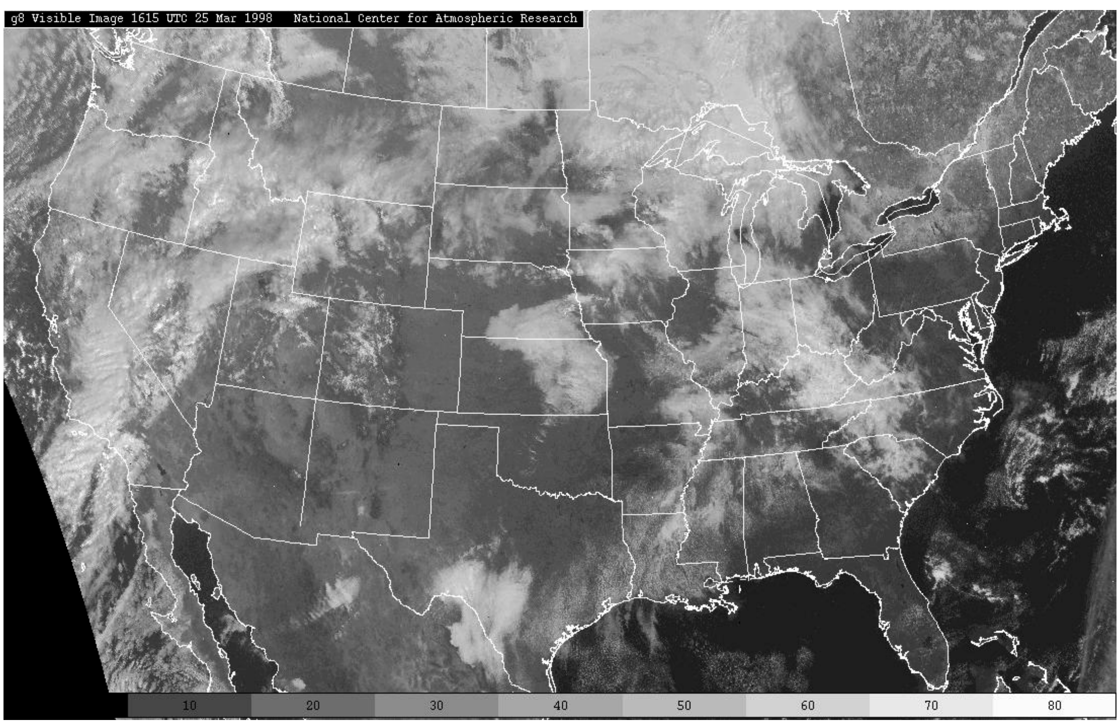
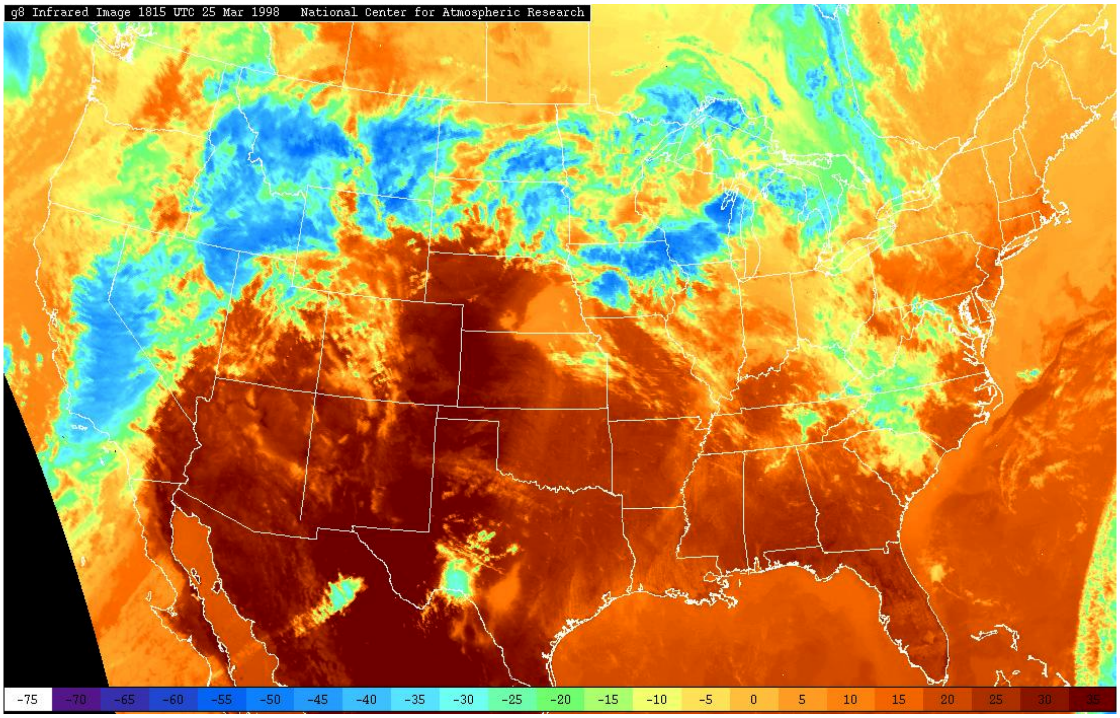


Figure 4 – GOES-8 d) infrared and e) visible satellite image for 980325, 1615 UTC.



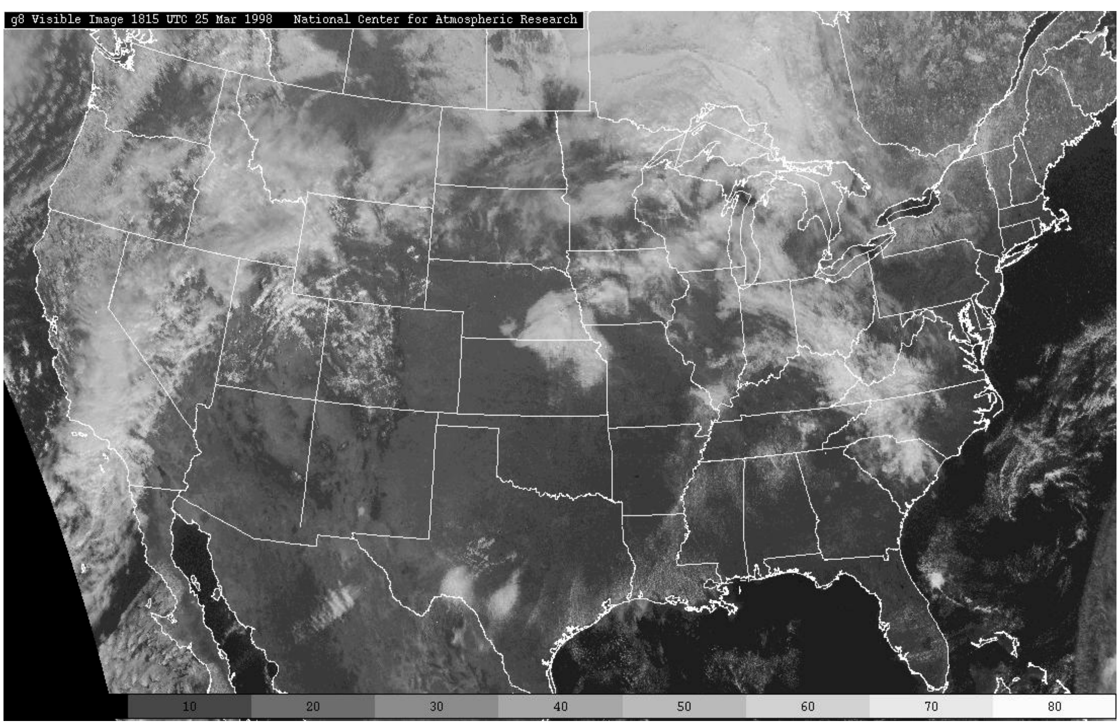
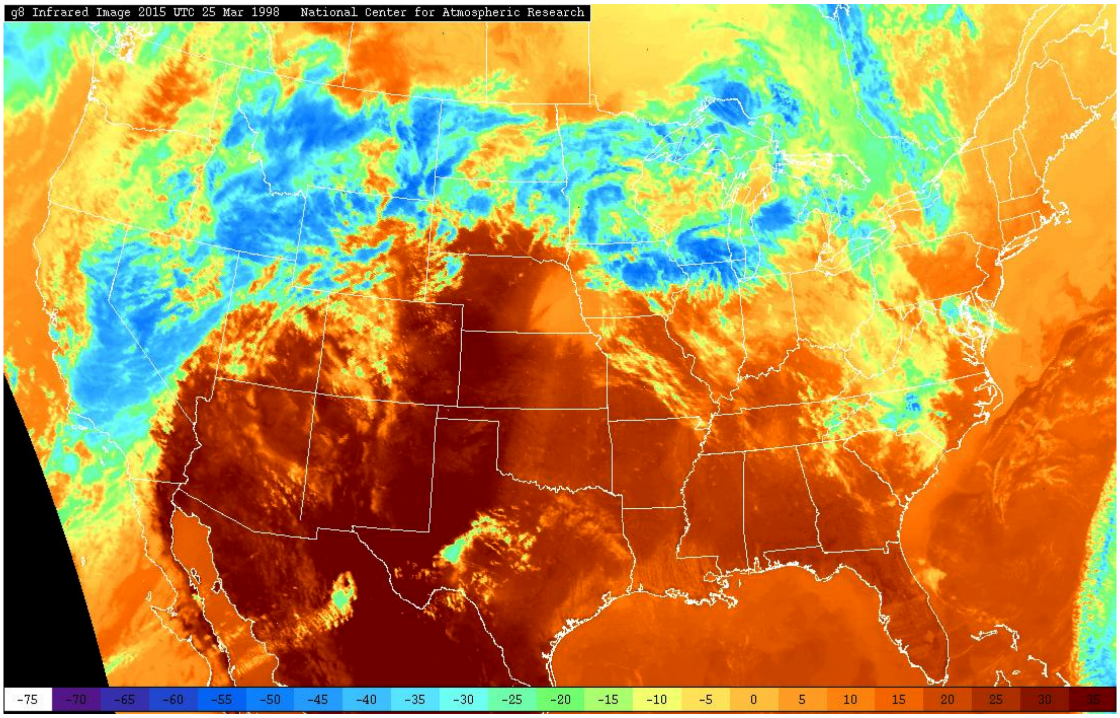


Figure 4 – GOES-8 f) infrared and g) visible satellite image for 980325, 1815 UTC.



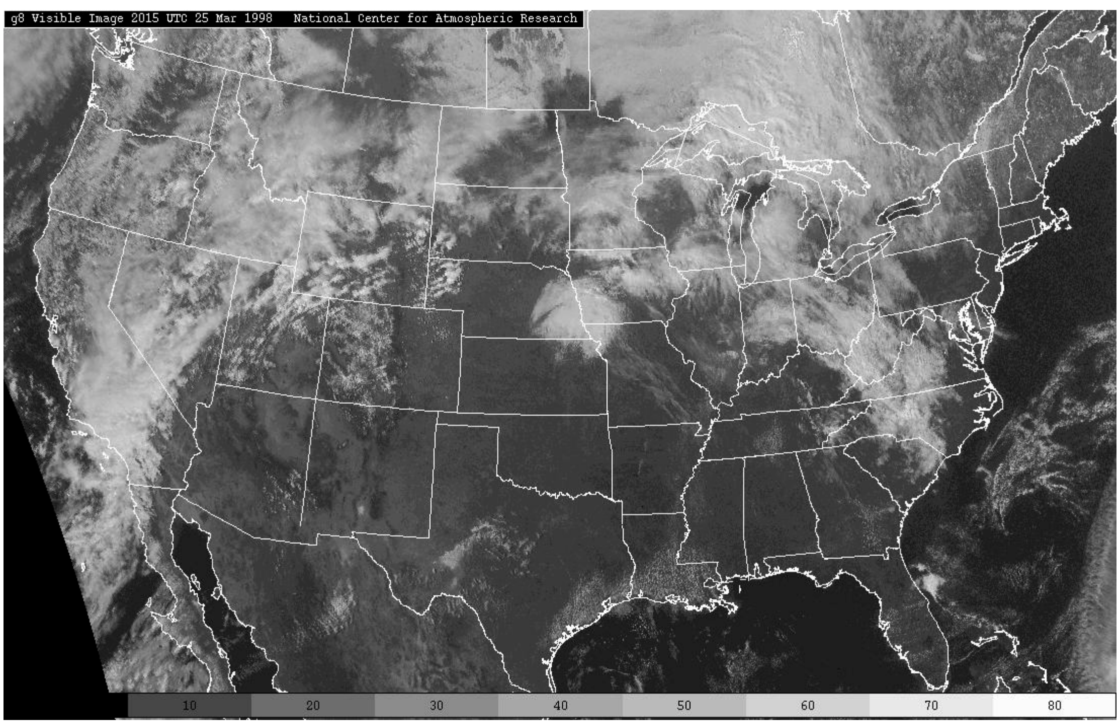
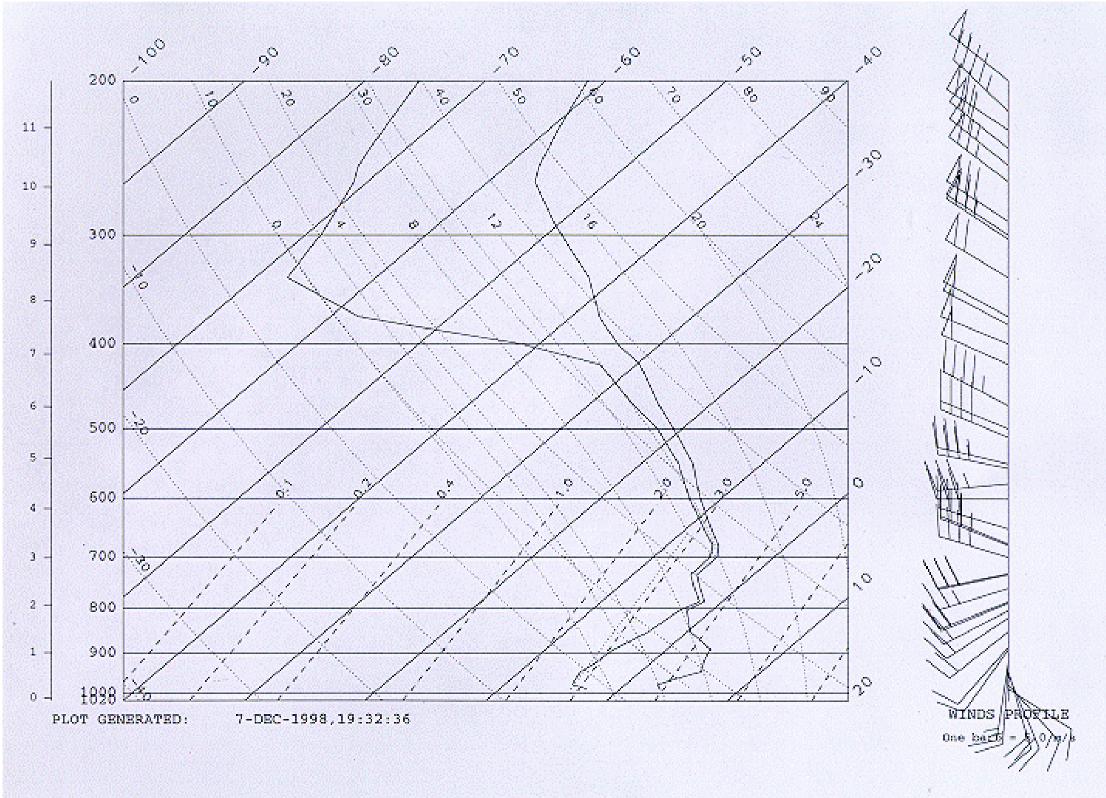


Figure 4 – GOES-8 h) infrared and i) visible satellite image for 980325, 2015 UTC.



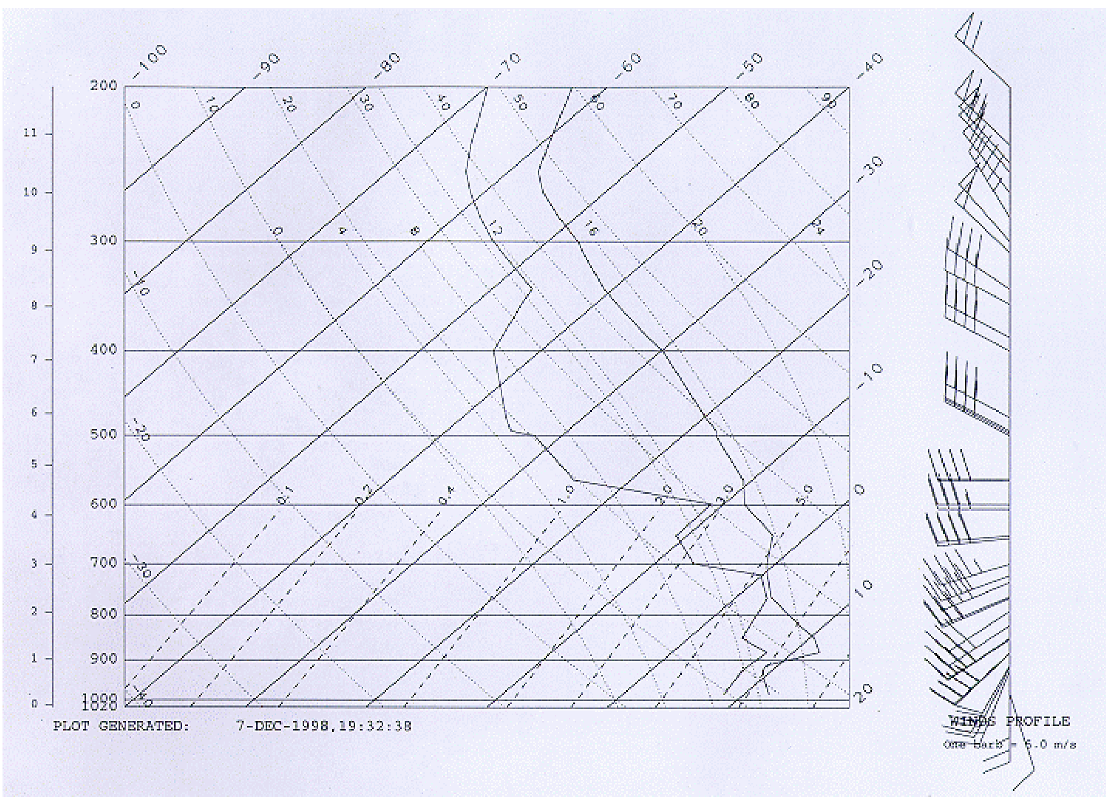
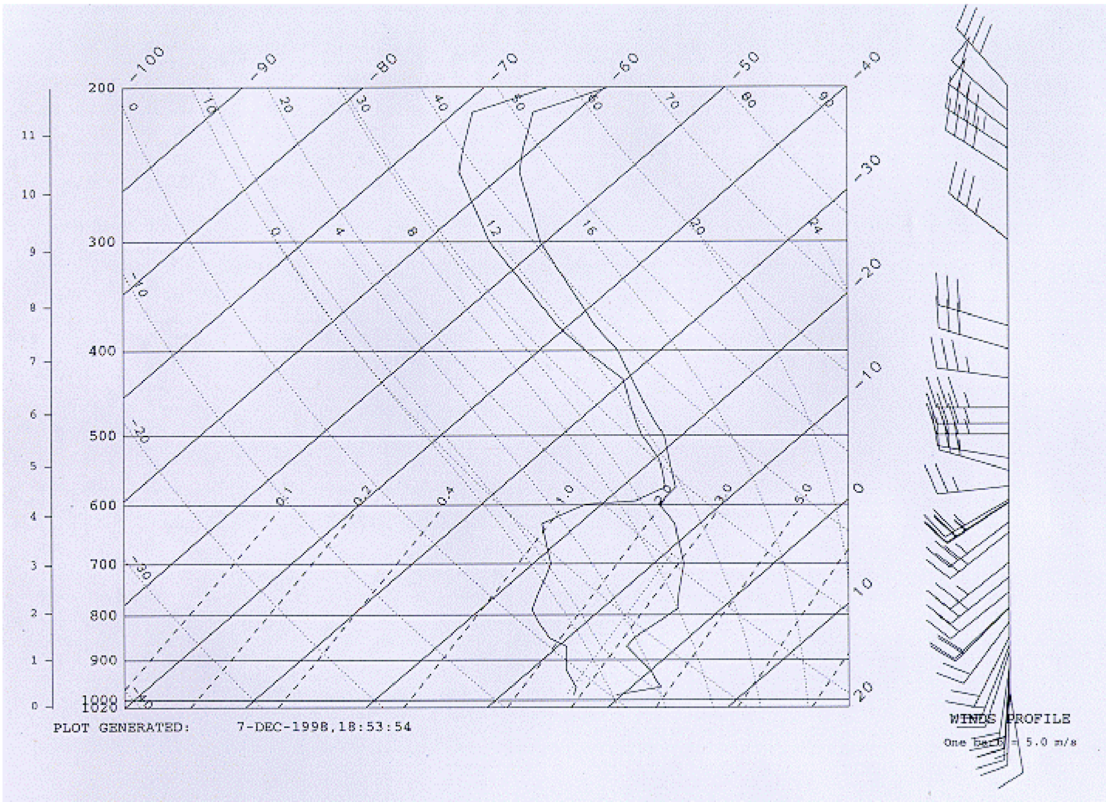


Figure 5 – Balloon-borne soundings from Wilmington at a) 980325, 1200 and b) 980326, 0000 UTC.



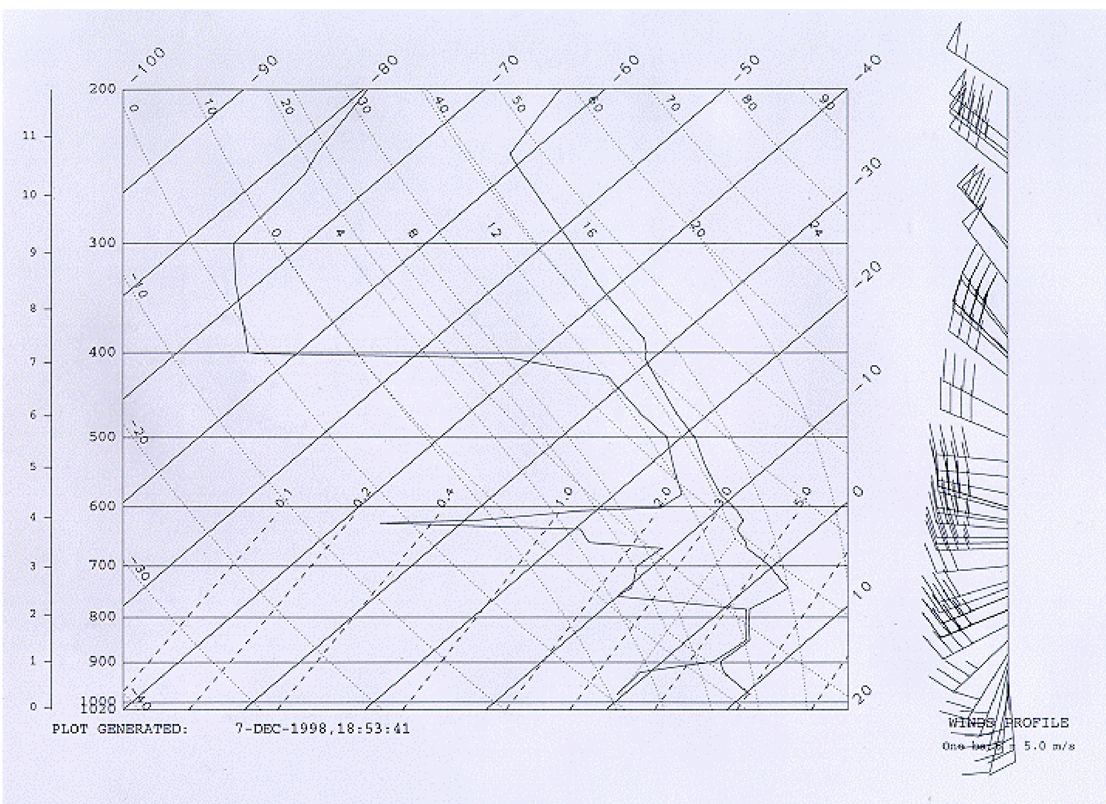
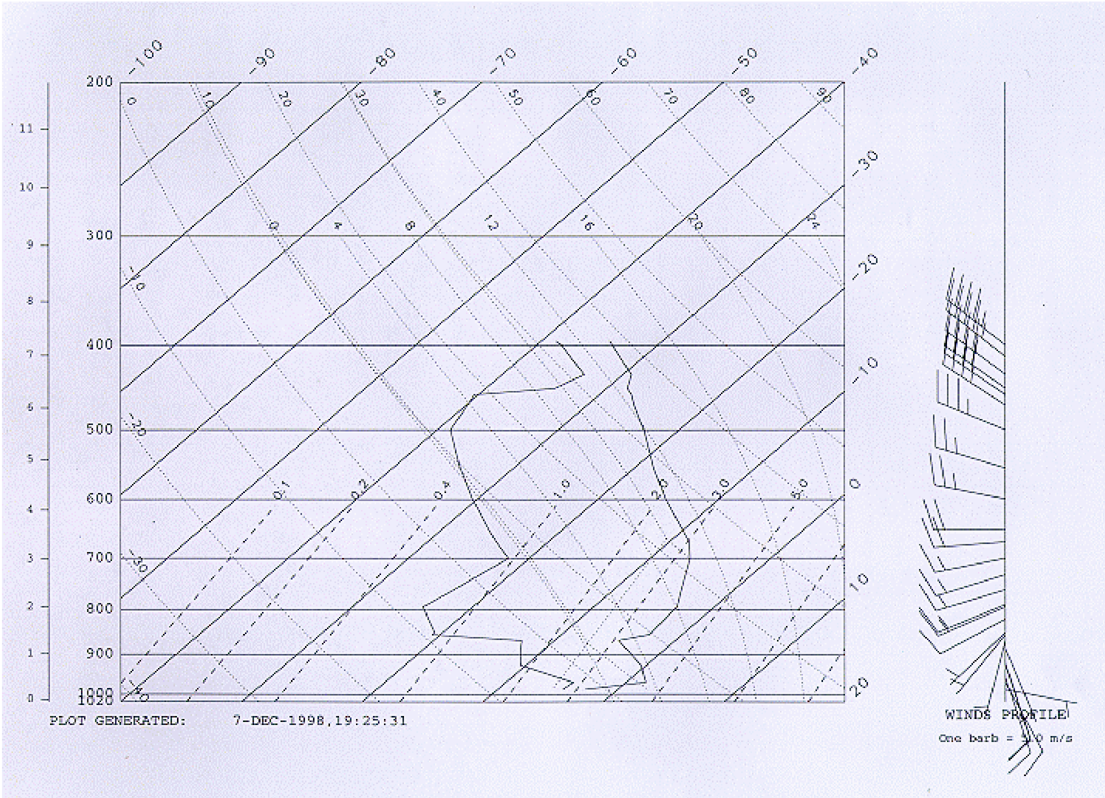


Figure 5 – Balloon-borne soundings from Detroit at c) 980325, 1200 and d) 980326, 0000 UTC.



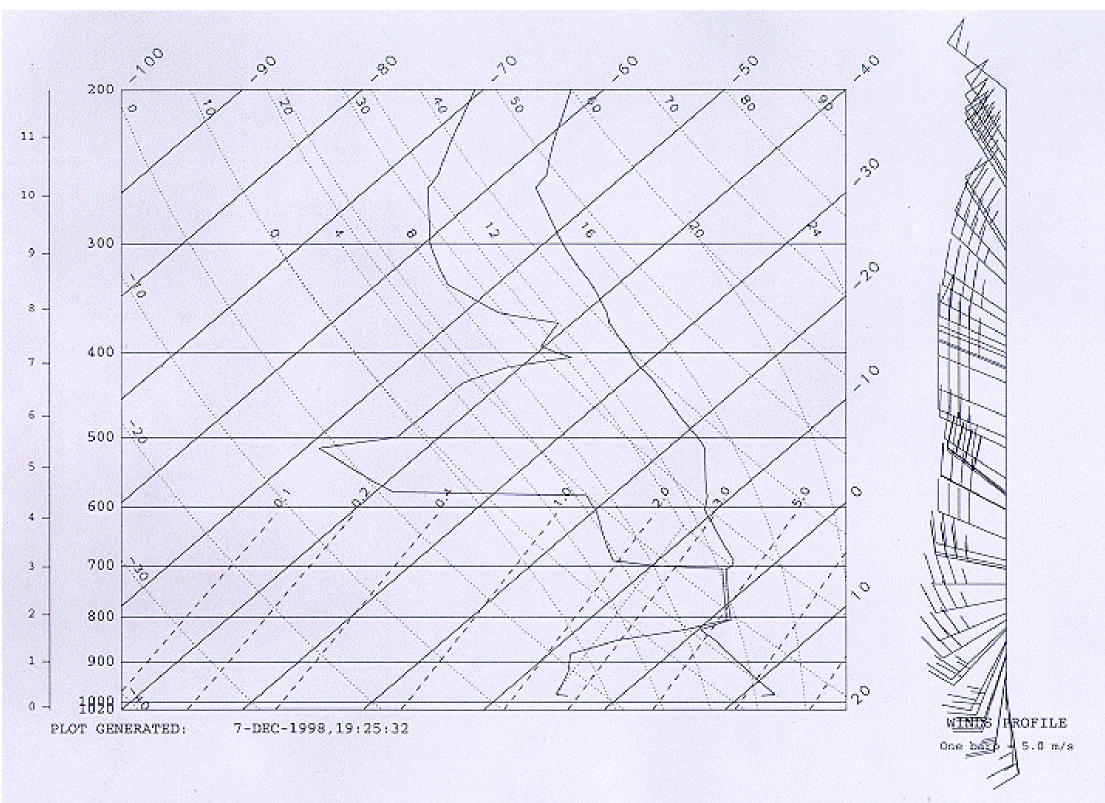


Figure 5 – Balloon-borne soundings from Pittsburgh at e) 980325, 1200 and f) 980326, 0000 UTC.

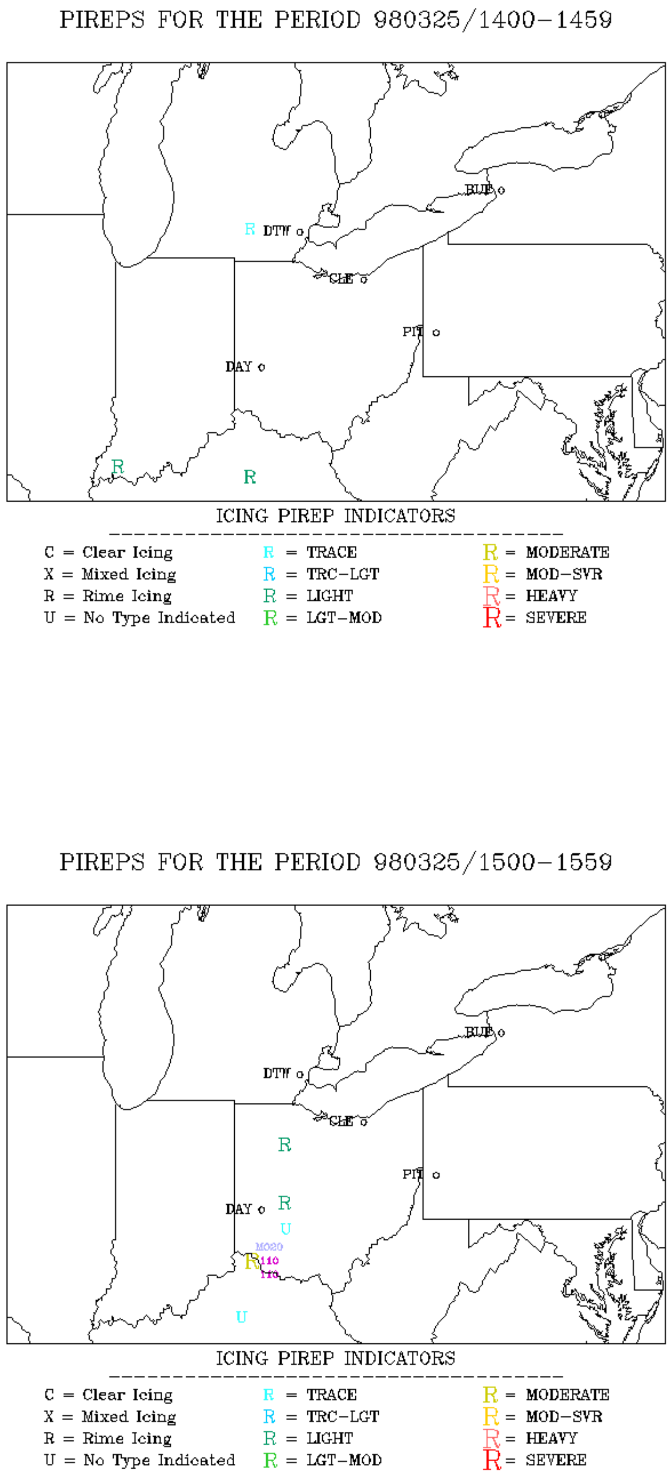
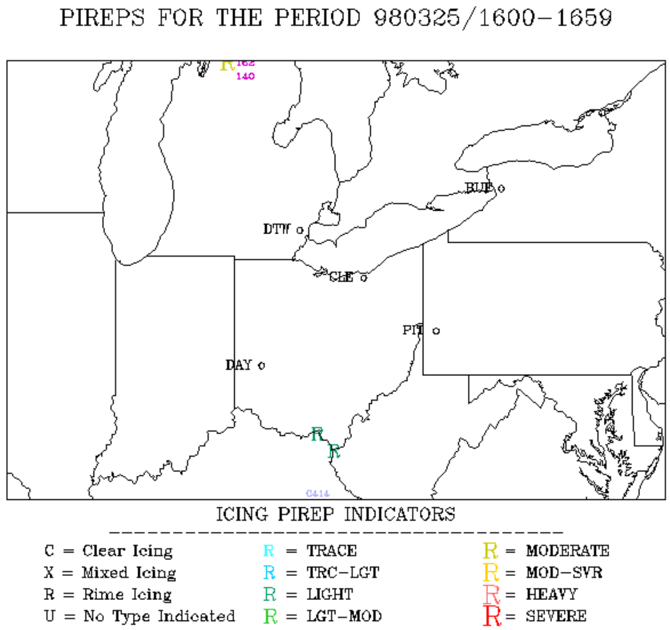


Figure 6 – Pilot reports of icing for 980325, a) 1400-1459 and b) 1500-1559 UTC.



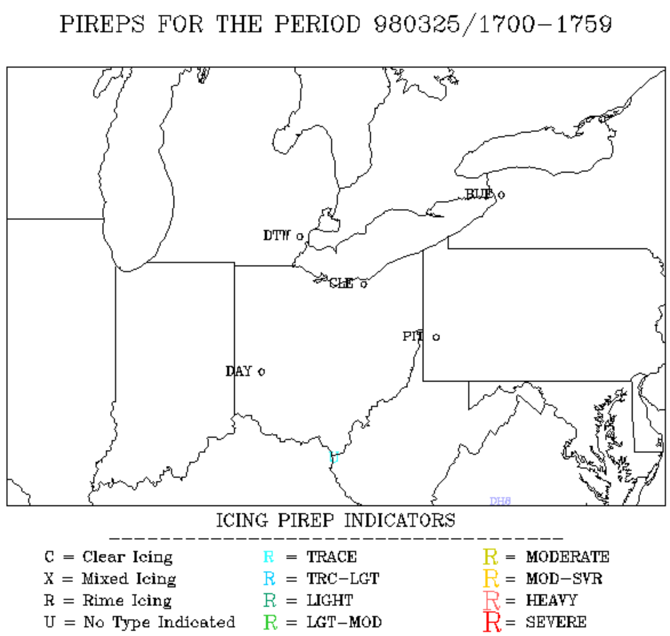
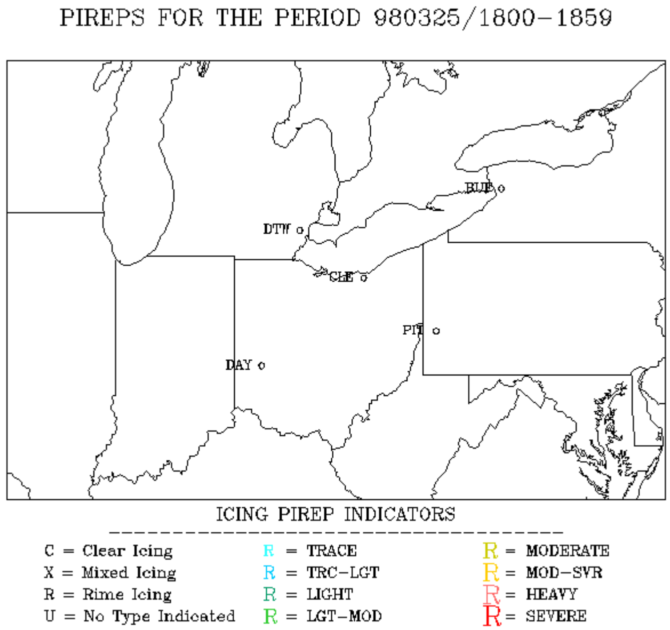


Figure 6 – Pilot reports of icing for 980325, c) 1600-1659 and d) 1700-1759 UTC.



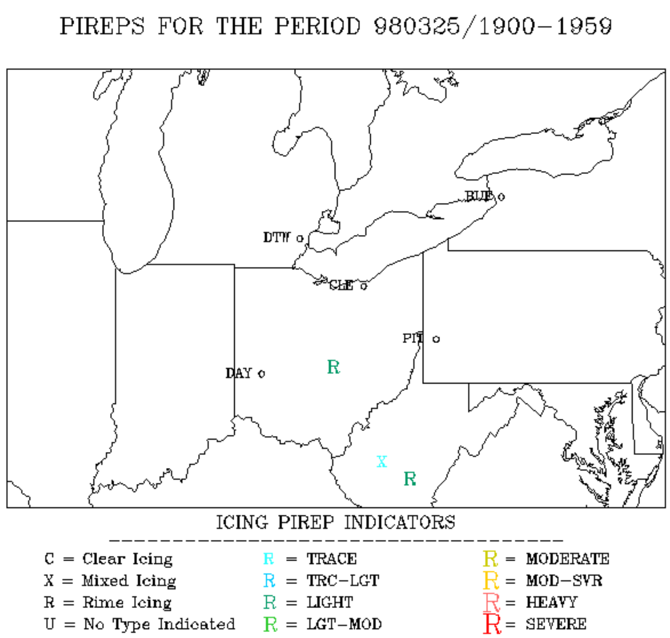


Figure 6 – Pilot reports of icing for 980325, e) 1800-1859 and f) 1900-1959 UTC.

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13. ABSTRACT ***(Maximum 200 words)***

This document contains a basic analysis of the meteorology associated with the NASA Glenn Twin Otter icing encounters between December 1997 and March 1998. The purpose of this analysis is to provide a meteorological context for the aircraft data collected during these flights. For each case, the following data elements are presented: (1) A brief overview of the Twin Otter encounter, including locations, liquid water contents, temperatures and microphysical makeup of the clouds and precipitation aloft, (2) Upper-air charts, providing hand-analyzed locations of lows, troughs, ridges, saturated/unsaturated air, temperatures, warm/cold advection, and jet streams, (3) Balloon-borne soundings, providing vertical profiles of temperature, moisture and winds, (4) Infrared and visible satellite data, providing cloud locations and cloud top temperature, (5) 3-hourly surface charts, providing hand-analyzed locations of lows, highs, fronts, precipitation (including type) and cloud cover, (6) Hourly, regional radar mosaics, providing fine resolution of the locations of precipitation (including intensity and type), pilot reports of icing (including intensity and type), surface observations of precipitation type and Twin Otter tracks for a one hour window centered on the time of the radar data, and (7) Hourly plots of icing pilot reports, providing the icing intensity, icing type, icing altitudes and aircraft type. Outages occurred in nearly every dataset at some point. All relevant data that was available is presented here. All times are in UTC and all heights are in feet above mean sea level (MSL).

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